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Section I
Workshop Lectures

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16. ABSTRACT

This document consists of the notebook supplied to each participant in the short course. It is divided into two main sections. Section I, contained herein, contains the nine workshop lectures. The lecture writeups provide information on how to utilize the Executive Program to meet specific user needs. Such needs may call for modification to or addition of a subroutine to the program. Section II contains the users' guide and program listing, and it describes how to use the main program and each of the 27 subroutines. This document describes the most recent version of the Executive Program. However, the continuing nature of the work in this area means that revision and additions are likely. These modifications will not change the basic structure of the program. Care should be taken to verify that the users' guide corresponds to the correct version of the Executive Program.

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*Models	*Cost effectiveness	Preliminary design	
Sewage treatment	Mathematical models	Computer program	
Design	Sewage treatment	Design engineering	
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Short Course Proceedings

APPLICATIONS OF COMPUTER PROGRAMS IN THE PRELIMINARY DESIGN OF WASTEWATER TREATMENT FACILITIES

Section I: Workshop Lectures

August 15-19, 1977
Illinois Institute of Technology
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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research--a most vital communications link between the research and the user community.

The purpose of this short course was to introduce and familiarize participants with the Executive Program for Preliminary Design of Wastewater Treatment Systems. The program is intended for use in the preliminary sizing and costing of the various components of a wastewater treatment plant. To best accomplish its intended purpose, the course was structured to fully involve the participants and encourage use of the program during the short course. Consequently, each workshop consisted of a short lecture describing some aspect of the Executive Program, followed by assignment of a problem. The participants then utilized the program to solve the specified problem. This hands on approach allowed considerable exposure to the Executive Program and extensive interaction with the short course faculty.

Francis T. Mayo
Director, Municipal Environmental
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ABSTRACT

This document contains the material used for the Short Course on the Applications of Computer Programs in the Preliminary Design of Wastewater Treatment Facilities. The users' manual describes the use of the program and subroutines. Several examples show appropriate input and expected output for a variety of applications. In addition, the theoretical background and computer listing are presented for the main program and each of the 27 subroutines.

Section I of this report contains the Short Course lectures. These workshops describe how to use, modify, and/or augment the Exec Program to meet the user's specific needs. Applications included: (1) the effect of design criteria selection, (2) multiple flow scheme cost and performance comparison, (3) the effect of economic parameter selection, (4) subroutine modification, (5) cost curve modification, (6) addition of new subroutines, (7) subroutine modification for simulation studies, and (8) use of a stream impact subroutine.

This report was submitted in partial fulfillment of Grant Number R-805134-01 by the Pritzker Department of Environmental Engineering at the Illinois Institute of Technology under the sponsorship of the U. S. Environmental Protection Agency. This report covers a period from May 23, 1977 to June 22, 1978 and work was completed as of June 22, 1978.

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THE ROLE OF COMPUTER PROGRAMS IN PRELIMINARY DESIGN

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ABSTRACT

Mathematical models in the form of computer programs have been developed for use in aiding the consulting engineer in producing cost-effective designs for wastewater treatment systems. These programs can assist the plant designer by supplementing his experience and judgment. Some of the programs are capable of doing both performance and cost analysis, and thereby minimize the computational work required for examining many alternate designs for achieving a desired effluent quality at a minimum cost. Easy access to computing facilities and relatively low usage cost make the idea of computer-aided design both desirable and practical.

INTRODUCTION

Since large-scale computers have now been available for 30 years, it is not necessary to discuss whether or not they are useful for design engineering applications. There are probably very few remaining areas of the engineering profession in general that do not make at least some use of computer programs, and the potential for computerized design techniques in planning wastewater treatment systems appears to be significant. However, only a modest effort has been made over the past ten years to develop practical computer software that can be used for this particular purpose. The main reason for this seems to be the more-or-less accepted attitude that no two treatment plant design situations are the same and, therefore, cannot be solved by a generalized system of computations. Human judgment based on experience is often looked upon as being of considerably more value than systemized computer calculations. Also, there is frequently strong resistance to changing established design methods and procedures. Thinking such as this can cause the planner to totally reject the idea of using preliminary design software in his activities. The important point that needs to be made is that computer programs should act as a supplemental tool to aid the engineer in performing his design work. The emphasis should be put on assisting and not on replacing the need for experience and judgment in wastewater treatment plant design. Since computers are not available to almost everyone and the cost of computing is extremely cheap (with respect to how much manual labor is eliminated), the wise engineer will make use of computerized techniques whenever these methods can be of assistance in solving design problems.

A computer program is basically a model. The system of procedure that it represents is described in mathematical form by means of a computer language, such as FORTRAN. Computer programs for preliminary design of wastewater treatment systems are models by which the performance of the system or its cost is studied by means of adjusting parameters that affect the calculations being performed. Preliminary design systems usually consist of a group of individual models that represent the different components of the system. These sub-models are then connected to one another by the flow scheme which joins the components of the real system. For simulation studies, the input parameters and the design of a particular treatment system are known, and a characterization of the system output is sought. The behavior of the system is observed as input data changes or as the mode of operation is varied. For design purposes, the inputs and outputs for the particular system are known, and a system configuration is sought which will satisfy the established requirements. The equipment required to do the job and the size of it can be determined with the design model. Both performance and cost are calculated for the desired system. In designing wastewater treatment plants, the problem often becomes one of finding the sizes, operating conditions, and cost of the unit processes which make up the system configuration. However, the type of plant design is often selected on the basis of tradition or the requirements of some regulatory agency, and not through cost-effective analysis.

COMPUTER-AIDED PROCESS DESIGN

Much more work in the area of computer-aided process design has been done in the chemical industry than in the waste treatment field. Computer-based process design has been commonly used by all the major oil companies and chemical producers for several years now. Some examples of various applications would be: propane recovery from natural gas, methanol synthesis, and ammonia production. Since many different design programs for the chemical industry have been developed and the fact that they are of little value for waste treatment design, only one of these programs will be described in order to give an idea of its structure and capabilities. Also, many of the chemical design programs are quite similar in various respects.

The CHESS(1) system was developed at the University of Houston and provides the user with some standard equipment subroutines for the most commonly used basic chemical process units and a thermodynamic properties evaluation routine for some 62 basic chemical components. Additional chemical components may be added. The system structure is so developed that it allows individual users to create and add their own equipment or process module subroutines if needed. Examples of some modules would be stream divider, distillation, mixing (several types), heat exchanger, compressor, absorber, etc. Examples of some chemical components would be hydrogen, methane, water, oxygen, carbon dioxide, etc. This model does not calculate any cost information; only performance. The program consists of 6500 source cards, written in FORTRAN, and takes 40K words on an SDS Sigma 7 computing system.

There also exists a limited number of executive programs that can be used for waste treatment studies. The simulation type models would be PACER(2), SEPSIM(3), GEMCS(4), and MACSIM (5). These are all essentially general purpose simulation executive programs which have been adapted for waste treatment systems by formulating a specialized library of subroutines. All are very similar in operation. PACER and MACSIM contain a network analysis routine which locates recycle loops in the flow scheme and organizes the iterative calculations needed for these loops. This portion can be bypassed if the user wants to specify a calculation scheme. GEMCS contains an optional subroutine to perform network analysis. SEPSIM has no network analysis capability, because it was developed for waste treatment systems which have simple networks allowing the order of calculation to be established by inspection. The design type models would be ESTHER(6) and ASOP(7). ASOP is a version of ESTHER which includes a pattern search routine and is capable of choosing a set of design parameters which will optimize an objective function that is chosen by the user. ESTHER is a combined design and simulation program which, through a user specified control value, selects the mode. The design mode calculates equipment sizes for a given effluent quality and various other outputs for each process until that is used in the system. ESTHER can handle a wide variety of waste treatment systems, but the user would probably have to develop the unit process models that are desired, since most work has centered around characterizing and optimizing the activated sludge process. The several executive programs mentioned thus far tend to be more academic than practical in that they were developed in a university atmosphere and little or no attention was given to calculating the costs associated with building and operating the designs which are produced. A thorough discussion and description of these computer programs is given in a Canadian report(8) on computer-aided design and simulation of waste treatment systems.

Two other design type models that provide both performance and cost information to the user are CAPDET(9) and EXEC(10). CAPDET allows the user to specify various types of unit processes for wastewater treatment. The unit processes together with their design parameters may then be assembled in sequence to form various versions of four types of treatment schemes. The program processes all combinations of unit processes and evaluates the treatment cost for each train. The trains are ranked according to least average annual cost. The calculated effluent quality is checked against the desired effluent characteristics, and those trains not meeting the desired quality are discarded. Cost data and design criteria are output from the program. The stream characteristics that are considered differ somewhat from those of EXEC; pH, °C, anions, cations, grease, etc. are included in CAPDET. This program contains certain unit processes not yet developed for EXEC (carbon adsorption, ammonia stripping, lagoons, etc.) and vice-versa (land disposal, lime addition to sludge, incineration, and rotating biological contactors). Standard inputs to the program are fixed unless changed by the user. CAPDET copies much of its content from EXEC, is not as flexible, is not as detailed, uses no iterative techniques, and requires a large-scale computing system. Its major value would be for comparing a large number of treatment alternatives. The Executive Program (EXEC) is the EPA-developed computer program for preliminary design of wastewater treatment systems which will form the basis of this short course-workshop. For this reason, a detailed discussion of the model background, development, uses, etc. will follow. The EPA has also created a number of other specialized design and cost-estimating programs for wastewater treatment, and these will also be discussed briefly.

MATHEMATICAL MODELING BY EPA

The Systems and Economic Analysis Section of the Wastewater Research Division of EPA in Cincinnati, Ohio is concerned with finding quantitative expressions for calculating the performance and cost of wastewater treatment processes as a function of the nature of the wastewater to be treated and the design variables associated with the individual unit processes. These models are intended primarily to characterize the treatment of municipal sewage. Since the procedure for solving all of the quantitative equations is usually too laborious or complex to be accomplished by hand calculation, various FORTRAN computer programs have been developed to perform the task.

BACKGROUND

Mathematical models for wastewater treatment processes are required to express the performance of the processes over the full range of operational modes and design criteria. These models can be steady state, quasi-steady state, or time-dependent. By quasi-steady state it is meant that a steady state model is used to simulate a process that is, in reality, not necessarily steady state. Most sewage treatment systems are not steady state. The time-dependent or dynamic models are of interest when the quality of the effluent stream from a process is important as a function of time, or when the effectiveness of various kinds of control schemes on a process is being studied.

For a model to be fully effective for design and planning purposes, it must be based on valid scientific principles, flexible enough to simulate experimental data from a full-scale process (not merely pilot-scale data), and represent the performance and cost of the process with adequate precision.

The collection of valid, complete experimental data followed by adjustment of the model parameters to make the computed results agree with experimental results within an acceptable tolerance is also an important phase of model development.

Packaging mathematical models as computer programs not only provides ease and accuracy of calculation, but also has the additional advantage of convenience of distribution to interested individuals, such as consulting engineers and urban planners, in a readily usable form.

MODELS DEVELOPED

Over the past eight years, a number of computer models have been developed in-house by the Systems and Economic Analysis Section and through contracting activity with outside sources. Each program deals in someway with cost and/or performance of wastewater treatment systems. All of the computer programs were written in FORTRAN and designed to run on a 16K IBM 1130 machine, and supporting documentation has been prepared for each. Table 1 gives a listing of the models which were produced in-house, and Table 2 shows the models which resulted from extramural sources. A brief description of the most significant of these computer programs will follow.

EXECUTIVE PROGRAM

The major product of all this effort has been the "Executive Digital Computer Program for Preliminary Design of Wastewaster Treatment Systems. It was realized that a tool was needed which would allow the process designer to select a group of unit processes, arrange them into a desired configuration, and then calculate the performance and cost of the system as a whole. The Executive Program meets this need by simulating groups of conventional and advanced wastewater treatment unit processes arranged in any logical manner. Each unit process is handled as a separate subroutine which makes it possible to add additional process models to the program as they are developed. There are presently 24 process subroutines in the program, and these are listed in Table 3. Additional subroutines are planned to be included in the future, and a tenative list is shown in Table 4.

The first step in using the Executive Program is to draw the desired system diagram showing the unit processes to be used and the connecting and recycle streams. All streams and processes are then numbered by the program user. Figure 1 depicts a typical, conventional activated sludge treatment system with incineration for sludge disposal. Volume and characteristics of the influent stream to the system and design varibles for each process used must be supplied as program input. By an iterative technique, each process subroutine is called in the proper sequence and all stream values are recomputed until the mass balances within the treatment system are satisfied. Performance, cost, and energy requirements for each unit process and the system as a whole are included in the final printout.

Detailed cost data applicable for preliminary design estimates is generated by the Executive Program. Construction cost (in dollars) amortization cost, operation and maintenance cost, and total treatment cost (all in cents per 1,000 gallons of wastewater treated) are calculated individually for every unit process, and a sum total of each cost is given for the entire

Table 1

COMPUTER PROGRAMS PRODUCED BY THE SYSTEMS AND ECONOMIC ANALYSIS SECTION

1. Preliminary Design and Simulation of Conventional Wastewater Renovation Using the Digital Computer (1968).
2. Executive Digital Computer Program for Preliminary Design of Wastewater Treatment Systems (1968).
3. A Mathematical Model for a Trickling Filter (1969).
4. Preliminary Design of Surface Filtration Units-Microscreening (1969).
5. A Generalized Computer Model for Steady State Performance of the Activated Sludge Process (1969).
6. Fill and Draw Activated Sludge Model (1969).
7. Mathematical Simulation of Ammonia Stripping Towers for Wastewater Treatment (1970).
8. Mathematical Simulation of Waste Stabilization Ponds (1970).
9. Simulation of the Time-Dependent Performance of the Activated Sludge Process Using the Digital Computer (1970).
10. Economics of Consolidating Sewage Treatment Plants by Means of Interceptor Sewers and Force Mains (1971).
11. Per Capita Cost Estimating Program for Wastewater Treatment (1971).
12. Wastewater Treatment Plant Cost Estimating Program (1971).
13. Design of Concrete and Steel Storage Tanks for Wastewater Treatment (1971).
14. Water Supply Cost Estimating Program (1972).
15. Cost of Phosphorus Removal in Conventional Wastewater Treatment Plants by Means of Chemical Addition (1972).
16. A Mathematical Model for Aerobic Digestion (1973).
17. Design and Simulation of Equalization Basins (1973).
18. Mathematical Model for Post Aeration (1973).
19. Optimum Treatment Plant Cost Estimating Program (1974).
20. Waste Stabilization Ponds Cost Estimating Program (1974).
21. Granular Carbon Adsorption Cost Estimating Program (1974).
22. Control Schemes for the Activated Sludge Process (1974).
23. Cost Estimating Program for Disinfection by Ozonation (1974).
24. Nitrification/Denitrification Cost Estimating Program (1975).

Table 1, Continued

25. Cost Estimating Program for Alternate Oxygen Supply Systems (1975).
26. Cost Estimating Program for Land Application Systems (1975).
27. Combustion Model for Energy Recovery from Sludge Incineration (1975).
28. Energy Consumption by Wastewater Treatment Plants (1975).
29. Stream Model for Calculating BOD and DO Profiles (1976).

Table 2

COMPUTER PROGRAMS PRODUCED AS A RESULT OF CONTRACT ACTIVITY

1. Ammonia Stripping Mathematical Model for Wastewater Treatment (1968).
2. Mathematical Model for Wastewater Treatment by Ion Exchange (1969).
3. Mathematical Model of the Electrodialysis Process (1969).
4. Mathematical Model of Tertiary Treatment by Lime Addition (1969).
5. Mathematical Model of Sewage Fluidized Bed Incinerator Capabilities and Costs (1969).
6. Reverse Osmosis Renovation of Municipal Wastewater (1969)
7. Methodology for Economic Evaluation of Municipal Water Supply/Wastewater Disposal Including Consideration of Seawater Distillation and Wastewater Renovation (1970).
8. Mathematical Model of Recalcination of Lime Sludge with Fluidized Bed Reactors (1970).
9. Computerized Design and Cost Estimation for Multiple Hearth Incinerators (1971).
10. Cost Program for Desalination Process (1971).

Table 3

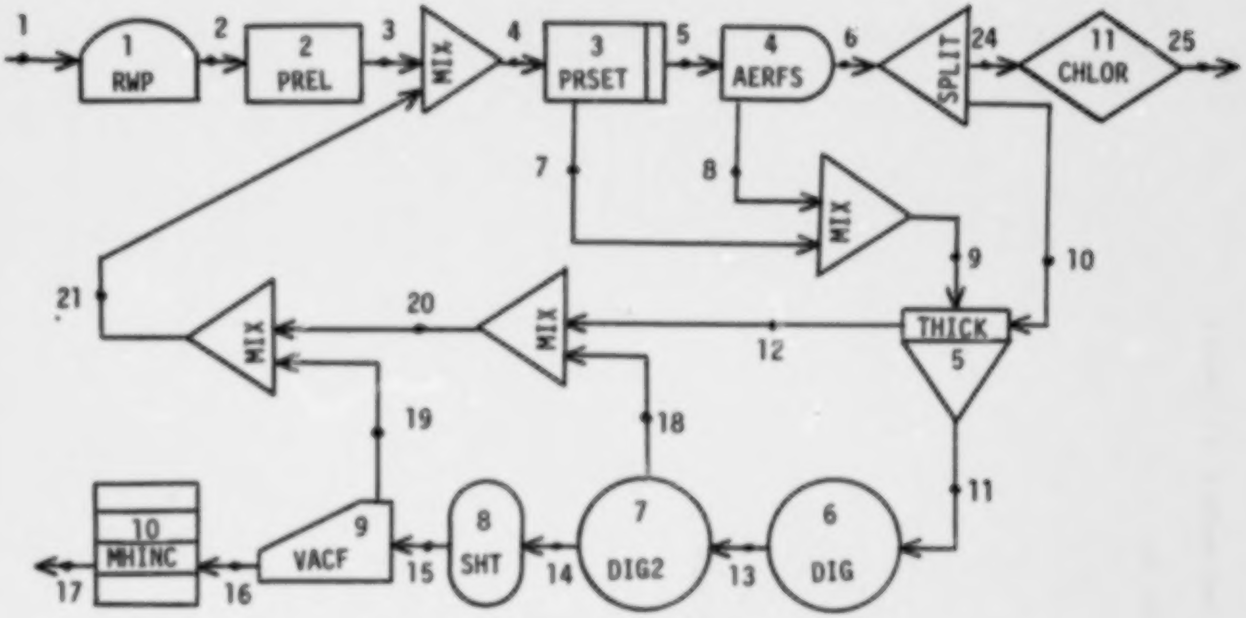
UNIT PROCESS MODELS CONTAINED IN THE EXECUTIVE PROGRAM

1. Preliminary Treatment
2. Primary Sedimentation
3. Activated Sludge-Final Settler
4. Stream Mixer
5. Stream Splitter
6. Single Stage Anaerobic Digestion
7. Vacuum Filtration
8. Gravity Thickening
9. Elutriation
10. Sand Drying Beds
11. Trickling Filter-Final Settler
12. Chlorination-Dechlorination
13. Flotation Thickening
14. Multiple Hearth Incineration
15. Raw Wastewater Pumping
16. Sludge Holding Tanks
17. Centrifugation
18. Aerobic Digestion
19. Post Aeration
20. Equalization
21. Second Stage Anaerobic Digestion
22. Land Disposal of Liquid Sludge
23. Lime Addition to Sludge
24. Rotating Biological Contactor - Final Settler

Table 4

UNIT PROCESS MODELS TO BE ADDED TO THE EXECUTIVE PROGRAM

1. Ammonia Stripping of Secondary Effluent
2. Granular Carbon Adsorption
3. Ion Exchange
4. Electrodialysis
5. Reverse Osmosis
6. Bar Screening
7. Comminution
8. Grit Removal
9. Flow Measurement
10. Waste Stabilization Ponds
11. Microscreening
12. Rough Filtration
13. Multi-Media Filtration
14. Ozonation
15. Nitrification
16. Denitrification


1
1 RWP
2
2 PREL
3
MIX
4
3 PRSET
5
4 AERFS
6
SPLIT
24
11 CHLOR
25
7
8
MIX
9
10
21
MIX
20
MIX
12
THICK 5
19
18
11
10 MHINC
9 VACF
8 SHT
7 DIG2
6 DIG
17
16
15
14
13

RWP - raw wastewater pumping
PREL - preliminary treatment
MIX - stream mixer
PRSET - primary sedimentation
AERFS - activated sludge/final settler
SPLIT - stream splitter
CHLOR - chlorination/dechlorination

THICK - gravity thickener
DIG - single stage anaerobic digestion
DIG2 - second stage anaerobic digestion
SHT - sludge holding tanks
VACF - vaccum filtration
MHINC - multiple hearth incineration

Figure 1

System diagram for a conventional activated sludge treatment plant system. Capital cost is also computed by adding onto construction expenses the costs of yardwork, land, engineering, administration, and interest during construction. All of the cost information can be updated or backdated with respect to time by means of cost indices that are supplied as input to the program.

The Executive Program cannot be used for extremely detailed design purposes. However, it can be a valuable preliminary design tool for the consulting engineer or planner. The performance of existing or proposed wastewater treatment plants can be simulated along with providing cost estimates for building and operating these plants. It is also possible to optimize a particular treatment system by varying design parameters and noting the effect on performance and cost. Cost-effectiveness studies can be made by comparing alternate treatment systems. Initial studies along these lines are becoming of increasing importance because of the soaring costs of plant construction that are now being experienced.

A recent application of the Executive Program was an investigation of the potential economic advantages associated with 261 different methods for treating and disposing of sewage sludge. Sludge production and the costs of constructing and operating the various systems were computed. Each system was either primary or activated sludge treatment followed by some combination of the following 12 sludge handling processes--lime stabilization, gravity thickening, air flotation thickening, single-stage anaerobic digestion, two-stage anaerobic digestion, aerobic digestion, elutriation, vacuum filtration, centrifugation, sludge drying beds, multiple hearth incineration, and land disposal of liquid sludge. The outcome of the study showed that the cost (in January 1974 dollars per ton of dry solids processed) for treating and disposing of sewage sludge ranges from about $30 per ton for anaerobic digestion followed by dewatering on sand drying beds to over $100 per ton when the sludge is dewatered by vacuum filtration or centrifugation and then incinerated. Treatment and disposal of sludges produced in municipal wastewater treatment plants were shown to account for as much as 60 percent or as little as 20 percent of the total cost of treatment. Therefore, careful consideration should be given to selecting the sludge handling method which meets the site-specific constraints at a minimum cost. The Executive Program, which is capable of examining the cost and performance of a wide variety of alternative sludge handling schemes, can be used as a management tool to narrow the range of options when design conditions are known.

The Executive Program has been around for several years now, beginning with its original development in 1968. The model has been expanded, modified, and corrected many times since then, and it will continue to change in the future. The goal will remain the same: to provide the best possible characterization of the cost and performance of municipal wastewater treatment systems.

MODELS FOR THE ACTIVATED SLUDGE PROCESS

Considerable effort has been expended in developing more accurate models for the activated sludge-final settling process. Previous models that were produced by various researchers covered a wide range of forms corresponding to differing sets of assumptions about the hydraulic and biological relationships believed to be significant in the process. Because of the problems of measurement and the difficulty of fitting data to complex models, simplified models were often used which either omit or make some plausible assumption concerning the role of various factors in the process.

In all, four different digital computer models for the activated sludge process have been developed. The first, CSSAS (Continuous Steady State Activated Sludge), is a steady state model which is flexible enough to simulate the performance of any configuration proposed (complete mix, plug flow, multiple aeration tanks, step aeration, step return flow, contact stabilization, extended aeration, etc). Two classes of microorganisms are considered: heterotrophs which use 5-day BOD as substrate and Nitrosomonas which use ammonia nitrogen as substrate to produce new cells. The model allows the maximum rate constant for synthesis to vary with process loading. The second program, FADAS (Fill and Draw Activated Sludge), attempts to simulate the biological activity in a fill and draw bench experiment where activated sludge is mixed with substrate in any proportion. The third program, TDAS (Time-Dependent Activated Sludge), simulates the dynamic behavior of the biological aspects of the activated sludge process. The model numerically integrates the mass balance and biological rate equations which are assumed to represent the process. Three classes of microorganisms are considered: heterotrophs, Nitrosomonas, and Nitrobacter. This model can also be used to investigate the potential advantages associated with the following control schemes: dissolved oxygen control, sludge wasting control, and sludge inventory control. The fourth program, CMAS (Completely Mixed Activated Sludge), is used to simulate the performance of conventional and modified activated sludge, separate nitrification, or separate denitrification. With an adjustment of the process parameters, it can also be used to characterize the pure oxygen activated sludge system.

SPECIALIZED COST ESTIMATING PROGRAMS

When making preliminary cost estimates for buiding and operating certain wastewater treatment systems, it is often necessary to have more detailed cost data. For this reason, special economic models were developed for several particular applications.

A waste stabilization pond cost estimating program computes the costs of stabilization ponds and aerated lagoons along with influent pumping, surface mechanical aerators, embankment protection, and chlorination facilities. The granular carbon adsorption cost estimating program calculates the costs of influent pumping, carbon contactors, regeneration facilities, and initial carbon required. The nitrification/denitrification cost estimating program predicts the costs of dispersed floc systems for the removal of nitrogen from wastewater. A cost estimating program for wastewater treatment by direct land application computes the costs of preapplication, distribution, renovated water recovery, and monitoring facilities. All of these economic models factor in the costs of yardwork, contingencies, engineering, land, administration, and interest during construction.

REQUESTS FOR THE MODELS

The real value of all these computer programs can be measured by their acceptance and use throughout the sanitary engineering field. These models and related work have experienced wide attention with many requests for descriptive reports and source card decks coming from consulting engineering firms, universities, states, municipalities, equipment manufacturers, other EPA offices, and various organizations interested in the simulation, design, and costing of wastewater treatment systems. Over 6000 copies of literature have been distributed during the last several years in response to requests. Perhaps a better measure of the applicability and need for this type of information is the fact that these requests have come from 47 of the 50 states and 32 different foreign countries. Much of this interest can be attributed to the fact that there are very few sources for complete,generalized cost and performance estimating procedures as applied to preliminary design of wastewater treatment processes.

Unfortunately, it is difficult to get good feedback as to how much use these computer programs are to the people that have expressed interest in them. However, enough feedback is obtained to assure that the work is being actively used in many areas. There are several universities presently using the models in their coursework. Many consulting engineering firms have modified some of the programs to fit their own particular needs. Area planners have used this work in urban development efforts. Various research and development literaure in the field cites this work as reference. EPA itself makes extensive use of the material.

Most of this information can be easily obtained through the National Technical Information Service (NTIS) or from EPA directly. Some of the computer programs and appropriate documentation are available through the Civil Engineering Program Applications (CEPA) organization.

CONCLUSION

The primary goal of this modeling effort is to improve the rule-of-thumb or hand calculation method of process design which is still commonly used today. The principal deterrents to better process design are usually the manual effort required in computing the cost and performance of alternative designs and the labor required to accumulate and correlate the large amount of expeirmental process design performance data which is often available. The mathematical computer model can minimize the computational work required for examining alternative designs, and, if the model has been correctly developed, it will reflect the best experimental and scientific information obtainable. Thus, the process designer has within his grasp the tools for quantitatively selecting the most cost-effective system of processes to achieve any desired wastewater treatment goal. The Systems and Economic Analysis Section within EPA is very much interested in promoting the use of computerized design techniques in order to achieve better treatment at a minimum cost.

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CASE I WORKSHOP

USE OF THE EXEC PROGRAM TO DETERMINE THE EFFECT OF DESIGN CRITERIA SELECTION ON PLANT COST AND PERFORMANCE

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ABSTRACT

Use of the Executive Program to evaluate the impact of design criteria selection on the cost and performance of a particular wastewater treatment system is presented. A method is presented for simplifying data assembly and program execution where more than one case is to be analyzed for a particular system. An example problem is presented in which the effects of the mixed liquor suspended solids concentration selected for design of conventional activated-sludge systems are evaluated and four analagous example problems are suggested.

INTRODUCTION

The purpose of this case study is to present a method for using the Executive Program to evaluate the effects of changing design criteria on the cost and performance of a particular treatment system, and to demonstrate the effect of design criteria selection on the results obtained using the Executive Program.

It is well recognized that the cost and performance of wastewater treatment systems can be substantially affected by the values of the parameters used in their design. Due to the massive amount of detailed computation involved in evaluating the effects of design criteria, time and financial constraints often limit the consideration which can be given to criteria selection. The Exec Program provides a means by which selected design criteria may be evaluated rapidly, at a relatively low cost.

STUDY APPROACH

The first step in evaluation of design criteria using the Exec Program should be establishment of a basic set of input data which contain the user's best approximation of the design parameter values which will result in the desired cost and performance of the system considered. The basic data file (or deck) may then be modified by copying it, then editing it to reflect changes in design criteria. Where card decks are used for input data, the card or cards containing the design parameter(s) to be changed would be replaced with a new card or cards containing the revised value of the parameter(s).

Using this method, a number of input data files may be assembled. Each file will be exactly the same as all of the others, except for the value(s) of the parameter(s) whose effects are being investigated. By copying data files, instead of retyping or punching them for each case, the chances of inadvertently changing the value of other parameters is reduced, and less time is required for data assembly.

After assembly of revised files for each value of the parameter(s) being changed, the files may be combined and results obtained for each case during a single execution of the Exec Program. When this is done, the combined input deck should be prefaced with a single card on which the number of cases to be tried is punched in the first two columns. Such cards should not be used at the beginning of each case. The above approach was used in this case study.

BASIC INPUT DATA

The basic input data presented in the following paragraphs was used in this Case Study. Values assigned to most of the parameters were selected by the author, but in some cases, it was necessary for IIT personnel to assign a value to a required parameter. This is because the version of the program with which the author has been working is not entirely similar to that being used at IIT. The values selected by IIT were based on recommended program input values.

Treatment System Considered

The example presented in this case study was based on use of the secondary treatment system shown schematically in Figure 1. The liquid treatment portions of the system consist of preliminary treatment, primary settling, a conventional activated-sludge system and chlorination. The sludge-handling system consists of gravity thickening of combined primary and waste-activated sludges followed by vacuum filtration. Sludge processing side streams are returned to the primary settling tanks. The input data used to describe this system are shown in Table 1.

The system was selected for its simplicity and was not intended to describe any particular treatment plant.

Raw Wastewater Characteristics

The values of the parameters which describe raw wastewater characteristics used for the purpose of this case study, their Exec Program variable names, assigned stream matrix (SMATX) locations, and definitions are shown in Table 2. The values shown are typical of those associated with medium strength domestic wastewater, as reported in various literature sources (3,4).

A raw wastewater flowrate of 10 mgd was selected in order to simplify comparison of results. A value of 200 mg/l was assumed for both influent BOD_5 and suspended solids. Influent BOD_5 was assumed to be 30 percent suspended and 70 percent volatile and the remainder fixed. The ratio of BOD_5 to organic carbon (both suspended and dissolved) was assumed to be 1.87, as suggested by Smith (5). Total influent phosphorus was assumed to be 10 mg/l of which 8 mg/l were assumed to be in the dissolved form. Very little information is available on the nonbiodegradable carbon content of domestic wastewaters. Values of 15 mg/l and 3 mg/l were assumed for settleable and dissolved alkalinity of 150 mg/l was assumed. Influent dissolved fixed matter was assumed to be 1,000 mg/l.

Basic Design Criteria

The design criteria for the processes and operations modeled by the Executive Program are defined by the user as part of the input data for each case considered. The criteria are stored on the computer in a decision matrix (DMATX). The criteria for a particular process or operation are stored in a single column of the matrix which is defined by the number assigned to the process or operation by the program user.

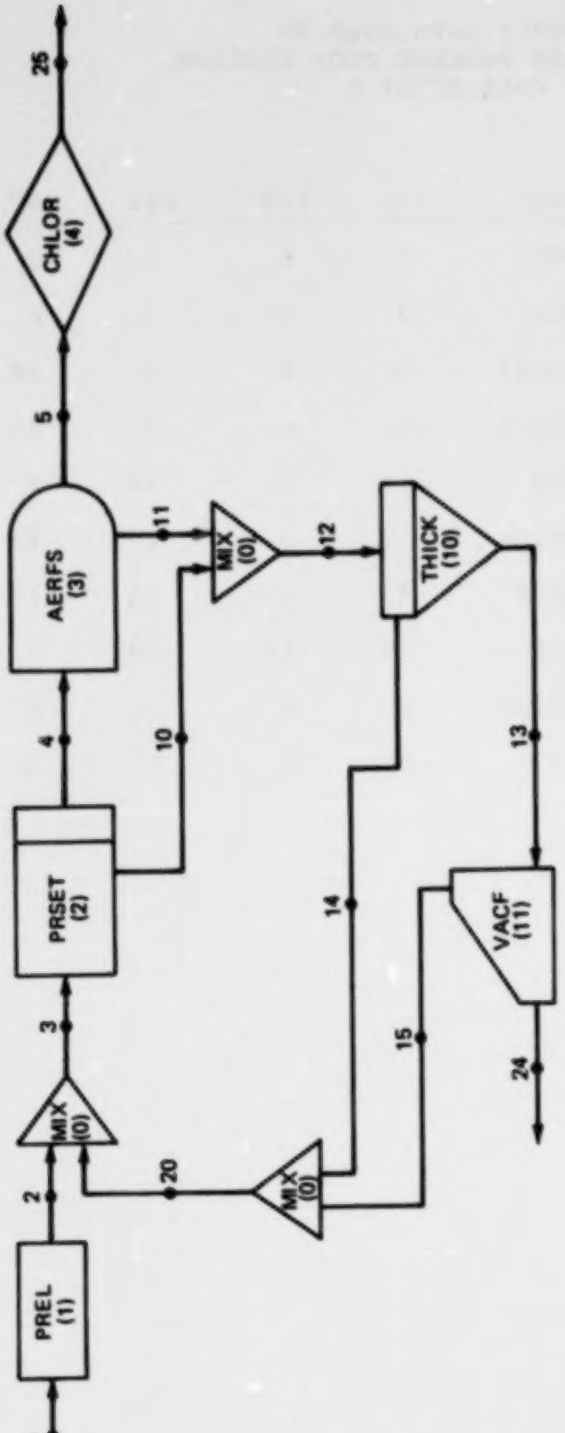
1
PREL (1)
2
MIX (0)
3
PRSET (2)
4
AERFS (3)
5
CHLOR (4)
25
10
11
MIX (0)
12
THICK (10)
13
VACF (11)
24
14
15
MIX (0)
20

FIG. 1 PROCESS FLOW DIAGRAM – CASE STUDY I

TABLE 1

INPUT DATA USED TO DESCRIBE PROCESS FLOW DIAGRAM
CASE STUDY I

K	N	IPROC	NAME	IS1	IS2	OS1	OS2	III
0	1	1	PREL	1	0	2	0	2
1	0	4	MIX	2	20	3	0	1
0	2	2	PRSET	3	0	4	10	0
0	3	3	AERFS	4	0	5	11	0
0	0	4	MIX	10	11	12	0	0
0	10	8	THICK	12	0	13	14	0
0	11	7	VACF	13	0	24	15	0
1	0	4	MIX	14	15	20	0	1
0	4	12	CHLOR	5	0	25	0	2
9	0	0	END	0	0	0	0	0

TABLE 2 CASE STUDY I

BASIC DATA FILE - RAW WASTEWATER CHARACTERISTICS

SYMBOL	MATRIX LOCATION	DESCRIPTION	ASSIGNED VALUE
Q	SMATX(2,1)	Flowrate for stream 1, mgd	10.0
SOC	SMATX(3,1)	Solid organic carbon content of stream 1, mg/l	33.0
SNBC	SMATX(4,1)	Solid nonbiodegradable carbon content of stream 1, mg/l	15.0
SON	SMATX (5,1)	Solid organic nitrogen content of stream 1, mg/l	5.0
SOP	SMATX(6,1)	Solid organic phosphorus content of stream 1, mg/l	2.0
SFM	SMATX(7,1)	Solid fixed matter content of stream 1, mg/l	60.0
SBOD	SMATX(8,1)	Solid BOD_5 content of stream 1, mg/l	60.0
VSS	SMATX(9,1)	Volatile suspended solids content of stream 1, mg/l	140.0
TSS	SMATX(10,1)	Total suspended solids content of stream 1, mg/l	200.0
DOC	SMATX(11,1)	Dissolved organic carbon content of stream 1, mg/l	74.0
DNBC	SMATX(12,1)	Dissolved nonbiodegradable carbon content of stream 1, mg/l	3.0
DN	SMATX(13,1)	Dissolved nitrogen content of stream 1, mg/l	25.0
DP	SMATX(14,1)	Dissolved phosphorus content of stream 1, mg/l	8.0
DFM	SMATX(15,1)	Dissolved fixed matter content of stream 1, mg/l	1000.0

TABLE 2 (Cont'd)

SYMBOL	MATRIX LOCATION	DESCRIPTION	ASSIGNED VALUE
ALK	SMATX(16,1)	Alkalinity of stream 1, mg/l as $CaCO_3$	150.0
DBOD	SMATX(17,1)	Dissolved BOD_5 content of stream 1, mg/l	140.0
NH3	SMATX(18,1)	Ammonia-nitrogen, mg/l	15.0(1)
NO3	SMATX(19,1)	Nitrate-nitrogen, mg/l	0.0(1)

---

1. Assigned by IIT.

Values which were selected for the basic design criteria for the processes and operations shown in Figure 1, their Exec Program variable names, DMATX locations, and definitions are shown in Table 3. Reasons for selection of key parameter values are discussed in the following paragraphs according to the process or operation considered.

Stream Mixers. Subroutine Mix does not provide treatment or involve cost, thus no DMATX input is involved. The function of this subroutine is computation of the characteristics of combined wastewater (or sludge) streams.

Preliminary Treatment. The preliminary treatment subroutine (PREL) contains only cost functions at this time. Thus, the only input parameters which are needed are (a) indication of the type of treatment, and (b) a value for the excess capacity factor (ECF) to be used in computing the costs of preliminary treatment.

Because the major cost item of preliminary treatment systems (Grit removal facilities) are normally provided in duplicate with each unit having the capacity to handle the full design flow conditions in plants of this size, a value of 2 was selected for the ECF of this operation.

Primary Settling. Because it is normally expected that primary settling will accomplish a 50 percent reduction in suspended solids, a value of 0.5 was selected for FRPS in subroutine PRSET.

Primary settling tanks may be operated to achieve varying degrees of thickening, with underflow solids (or primary sludge) commonly having a concentration of between 10,000 and 50,000 mg/l. An underflow solids concentration of approximately 35,000 mg/l was selected, yielding a value of 175 for URPS.

The excess capacity factor selected for settling tanks should reflect expected peak flow, the number of tanks which might be installed at facilities of the size investigated, and the frequency at which peak flows are expected. Normal practice indicates that an ECF of 1.2 to 1.3 is acceptable. A value of 1.25 was selected for this study.

Activated Sludge System. Subroutine AERFS models the performance of a conventional activated-sludge system consisting of an aeration tank(s) and a final settling tank(s). The model assumes operation at steady-state. The values associated with the required input parameters were selected on this basis and are individually discussed below:

TABLE 3

BASIC DATA FILE
DECISION MATRIX (DMATX) CONSTANTS - CASE STUDY I

SYMBOL	DMATX LOCATION	DESCRIPTION	ASSIGNED VALUE
COST CONSTANTS			
CCI	1,20	EPA STP construction cost index (1957-59 = 1.0)	2.6
WPI	2,20	Wholesale price index for industrial commodities (1957-59 = 1.0)	1.926(1)
RI	3,20	Fractional interest rate	0.0575(1)
YRS	4,20	Amortization period, yrs.	30.0(1)
DHR	5,20	Hourly wage rate, $/hr.	5.0(1)
PCT	6,20	Fractional indirect labor cost	0.15(1)
DA	7,20	Land cost, $/Acre	2500.0(1)
CCINT	8,20	Fractional interest during construction	0.06(1)
XLAB	9,20	Laboratory requirements	1(1)
CKWH	10,20	Electrical energy cost, $/KWH	0.04
SUBROUTINE PREL			
IPREL	1,1	Type preliminary treatment	1
ECF	16,1	Excess capacity factor for preliminary treatment	2.0
SUBROUTINE PRESET			
FRPS	1,2	Desired suspended solids removal efficiently (fractional)	0.5
URPS	2,2	TSS of 0S2/TSS of IS1	175.0
SUBROUTINE PRESET			
HPWK	3,2	Weekly hours of operation at primary sludge pumps	14.0(1)
PSP ECF	15,2	Excess capacity factor - primary sludge pumps	1.25(1)
PST ECF	16,2	Excess capacity factor for primary settling tank	1.25
SUBROUTINE AERPS			
BOD5	1,3	Desired secondary effluent BOD5 (SBOD + DBOD), mg/1	25.0
XMLSS	2,3	Design aeration tank mixed liquor suspended solids level, mg/1	2.000.0

TABLE 3 (Cont'd)

BASIC DATA FILE
DECISION MATRIX (DMATX) CONSTANTS - CASE STUDY I

SYMBOL	DMATX LOCATION	DESCRIPTION	ASSIGNED VALUE
DEGC	3,3	Operating temperature of activated sludge system, deg. C	20.0
CAER20	4,3	Rate constant to be used in sizing the aeration tank expressed as a fraction of 0.024 (lb MLSS-day)$^{-1}$	1.0
DO	5,3	Operating aeration tank dissolved oxygen level, mg/l	2.0
AEFF20	6,3	Fractional oxygen transfer efficiency of diffused air system	0.06
URSS	7,3	TSS of OS2/XMLSS	3.75
GSS	8,3	Design Clarifier overflow rate, gpd/s.f.	750.0
HEAD	9,3	TDH on return sludge pumps, ft.	30.0
ALMD	10,3	Alum dose, mg/l (for phosphorus removal)	0.0
SUBROUTINE AERFS			
FST ECF	13,3	Excess capacity factor for secondary settling tank(s)	1.2
RSP ECF	14,3	Excess capacity factor for return sludge pump(s)	2.0
BL ECF	15,3	Excess capacity factor for blower(s)	1.5
AT ECF	16,3	Excess capacity factor for aeration tank(s)	1.25
SUBROUTINE THICK			
TRR	1,10	Fractional solids capture	0.90
TSS14	2,10	TSS content of thickened sludge, mg/l	50,000.0
GTH	3,10	Thickener overflow rate, gpd/sf.	100.0
GSTH	4,10	Solids loading rate on thickener, lb/day/s.f.	25.0
ECF	16,10	Thickener excess capacity factor	1.75
SUBROUTINE VACF			
VFL	1,11	Vacuum filter loading, gph/s.f.	7.6

TABLE 3 (Cont'd)

BASIC DATA FILE
DECISION MATRIX (DMATX) CONSTANTS - CASE STUDY I

SYMBOL	DMATX LOCATION	DESCRIPTION	ASSIGNED VALUE
HPWK	2,11	Weekly hours of operation	35.0
TSS15	3,11	Expected filtrate solids concentration, mg/l	2000.0
IVACF	4,11	Program control, 0 = land fill, 1 = incineration	1.0(1)
FECL3	5,11	Ferric chloride dose, lb/Ton dry solids	42.0
CAO	6,11	Lime dose, lb/Ton dry solids	0.0(1)
SUBROUTINE VACF (cont'd)			
CFECL	7,11	Ferric chloride cost, $/lb.	0.05
CCAO	8,11	Lime cost, $/lb.	0.0125(1)
DPOLY	9,11	Polymer dose, lb/Ton dry solids	0.0(1)
CPOLY	10,11	Polymer cost, $/lb.	0.33(1)
ECF	16,11	Excess capacity factor	1.5
SUBROUTINE CHLOR			
DCL2	1,4	Chlorine dose, mg/l	8.0
TCL2	2,4	Detention time in CCT, min.	30.0
CCL2	3,4	Chlorine cost, $/Ton	300.0
DSO2	4,4	Sulfur dioxide dose, mg/l	0.0
CSO2	5,4	Cost of sulfur dioxide, $/Ton	180.0
ECF-SO2	14,4	Excess capacity factor for sulfur dioxide feed system	1.0
ECF-CLF	15,4	Excess capacity factor for chlorine feed system	1.0
ECF-CCT	16,4	Excess capacity factor for chlorine contact tank	1.0

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1. Assigned by IIT

1. Desired secondary effluent BOD_5.

   Present EPA standards require that 7 consecutive day average effluent BOD_5 from secondary treatment facilities not exceed 30 mg/l. In order to allow a margin of safety, an effluent BOD_5 of 25 mg/l was selected.

2. Desired operating MLSS concentration.

   A nominal MLSS concentration of 2,000 mg/l was selected. This value is fairly typical of those used in design of conventional activated-sludge systems.

3. System operating temperature.

   Normally, a value which reflects some worst-case operating temperature would be selected (lowest 10 year, etc.). For simplicity, a temperature of 20^oC was selected.

4. Biological reaction rate constant.

   In subroutine AERFS, system kinetics have been defined by use of a version of the Michaelis-Menton equation. Based on the authors knowledge of subroutine AERFS, the value of the rate constant at 20^oC (CAER20) which must be supplied as input should be expressed as a fraction of the value 0.024 $(\text{lb MLSS-day})^{-1}$. This value (0.024) was evidently emperically determined (7) to be typical of conventional activated-sludge systems treating domestic wastewater. A value of 1.0 was selected for CAER20, as suggested by Smith and Eilers (1,2).

5. Operating aeration tank DO level.

   Normal design practice utilizes values of 1 to 2 mg/l for operating DO. A value of 2 mg/l was selected.

6. Fractional efficiency of aeration equipment at 20^oC.

   The normal operating efficiency of diffused air aeration systems varies from 4 to 7 or 8 percent. An efficiency of 6 percent (0.06) was selected.

7. Secondary sludge solids content.

   In subroutine AERFS, secondary sludge solids content (URSS) is expressed as a fraction of MLSS. Conventional activated-sludge systems may be expected to produce sludges with a solids content of between 0.5 and 1.0 percent. A value of 0.75 percent (7,500) mg/l was selected, resulting in a value of 3.75 for URSS.

8. Desired secondary settling tank overflow rate.

   Design overflow rates for conventional activated-sludge systems are typically between 600 and 800 gpd/sf at average flow. A value of 750 was selected.

9. Expected total dynamic head on return sludge pumps.

   For the purpose of this case study, the value of 30 feet recommended by Smith and Eilers was selected (2).

10. Alum dose used for phosphorus removal.

    Phosphorus removal was not considered herein, thus a value of 0.0 was used for ALMD.

11. Final settling tank ECF.

    For reasons presented in the section on primary settling, a value of 1.2 was selected.

12. Return sludge pump ECF.

    On numerous occasions, return sludge pumping capacity far in excess of that encountered during normal operation is required. Extended peak flows, pollutant loads or plant upsets such as bulking sludge can occasion such use. For this reason, an ECF of 2.0 was selected for the return sludge pumps.

13. Aeration tank ECF.

    The excess capacity factor used for aeration tank sizing should be based on expected performance under some peak loading condition. For the purposes of this case study, a value of 1.2 was selected.

Chlorination. Subroutine CHLOR does not consider treatment. Its purpose is to compute the size and costs of the desired chlorination system. The selected values of the sizing parameters were based on values commonly used in conventional chlorination systems.

Gravity Thickening. The values of the design parameters selected for subroutine THICK are not typical of those normally used for design. They were selected to demonstrate that computed process performance is dependent upon input data.

Vacuum Filtration. Values for the design parameters required by subroutine VACF are typical of those reported in current EPA literature (6).

EXAMPLE PROBLEM

A question frequently considered during preliminary design of activated-sludge systems is whether or not costs can be optimized by adjustment of the value selected for aeration tank mixed liquor suspended solids concentration (MLSS). Although it is recognized that higher MLSS concentrations will result in reduced volume requirements for the secondary reactor, other portions of the treatment system such as return sludge pumps, blowers, clarifiers, and the sludge-handling system may also be affected. The quantitative effects of alternative MLSS levels on each portion of the system are difficult to evaluate without first performing a materials balance on the selected system at a number of MLSS levels.

This example problem demonstrates use of the Exec Program to evaluate the effects of various MLSS values.

Input Data

In order to establish general trends associated with changesin MLSS values, five cases were tried. The first case consisted of the basic data previously described. In the remaining cases, only the value of MLSS was changed. Values selected for MLSS were 1,600, 1,800, 2,000 (per basic data), 2,200, and 2,400.

Output Results

Pertinent Exec Program output reflecting overall system performance and cost are shown in Table 4. Output which reflects the cost, performance and size of the individual processes and operations is shown in Table 5.

Minimal statistical analysis of the results was performed. The average value of pertinent results and the range of calculated values as a percent of the average were calculated and are also shown in Tables 4 and 5. The later value was calculated to indicate the relative variability of each of the parameters listed in the tables.

Overall System Output

As shown in Table 4, Exec Program output values for system cost and performance are not substantially affected by changes in MLSS alone. Sludge production and general characteristics were the same for each value of MLSS used. Total effluent BOD is the same for all cases (as would be expected since it was set as part of program input). The type of effluent BOD is slightly affected by the selected MLSS value, lower MLSS values being associated with higher effluent suspended BOD values and lower effluent dissolved BOD values. This is further reflected in the

TABLE 4 EXAMPLE PROBLEM RESULTS - CASE STUDY I

COMPUTED VALUES OF MAJOR SYSTEM PARAMETERS AT VARIOUS MLSS VALUES

PARAMETER	MLSS(mg/l)						Range as percent of average(1)
	1600	1800	2000	2200	2400	Average	
STREAM 24 (sludge production)							
TSS,%	28	28	28	28	28	28	0.0
TSS, lb/day	18,700	18,700	18,700	18,700	18,700	18,700	0.0
VSS,% TSS	70	70	70	70	70	70	0.0
STREAM 25 (system effluent)							
Q, mgd	9.99	9.99	9.99	9.99	9.99	9.99	0.0
SBOD, mg/l	9.2	8.8	8.4	8.1	7.8	8.5	16.0
DBOD, mg/l	15.7	16.1	16.5	16.8	17.2	16.5	9.0
TBOD, mg/l	24.9	24.9	24.9	24.9	25.0	24.9	0.4
TSS, mg/l	19.9	19.1	18.2	17.6	17.0	18.4	15.8
STREAM 20 (principal recycle)							
Q,mgd	0.25	0.22	0.20	0.19	0.17	0.21	38.8
TBOD, lb/day	1,123	1,112	1,126	1,142	1,100	1,121	3.7
TSS, lb/day	2,712	2,692	2,732	2,775	2,677	2,718	3.6
SYSTEM COSTS (¢/1000 gal.)							
TAMM	10.7	10.6	10.5	10.4	10.3	10.5	3.8
TOPER	9.8	9.8	9.8	9.8	9.8	9.8	0.0
TOTAL	20.5	20.4	20.3	20.2	20.1	20.3	2.0

1. $\frac{\text{Max.-Min.}}{\text{Avg.}}$ (100)

TABLE 5. EXAMPLE PROBLEM RESULTS - CASE STUDY I
COMPUTED VALUES OF MAJOR PROCESS PARAMETERS
AT VARIOUS MLSS VALUES

PARAMETER	MLSS (mg/l)					Average	Range as percent of average[1]
	1600	1800	2000	2200	2400		
SUB. PREL							
TCOST (¢/1000 gal.)	1.36	1.36	1.36	1.36	1.36	1.36	0.0
SUB. PRSET							
APS, 1000 s.f.	9.31	9.29	9.28	9.26	9.25	9.28	0.6
PGPM, gpm	305	304	304	303	303	304	0.6
Q4, mgd	10.22	10.19	10.18	10.16	10.14	10.18	0.8
TBOD4, lb/day	14,734	14,898	14,765	14,724	14,730	14,770	1.2
TSS4, lb/day	9,697	9,697	9,674	9,709	9,713	9,698	0.4
Q10, mgd	0.03	0.03	0.03	0.03	0.03	0.03	0.0
TSS10, % solids	4.0	4.0	4.0	4.0	4.0	4.0	0.0
SUB. AERFS							
VAER, mil. gal.	1.97	1.75	1.58	1.43	1.31	1.61	41.0
BSIZE, cfm	8,547	8,525	8,494	8,475	8,453	8,499	1.1
QR, mgd	3.36	3.39	3.42	3.44	3.45	3.41	2.6
AFS, 1000 s.f.	16.0	16.0	16.0	16.0	16.0	16.0	0.0
XRSS, n.d.	0.0125	0.0106	0.0092	0.0080	0.0071	0.0095	57.0
Q11, mgd	0.226	0.202	0.183	0.167	0.153	0.186	39.2
TSS11, % solids	0.60	0.67	0.75	0.82	0.90	0.75	40.1
TSS11, lb/day	11,266	11,360	11,392	11,461	11,445	11,385	1.6
VSS11, % TSS	78	78	78	78	78	78	0.0

1. $\frac{\text{Max.-Min.}}{\text{Avg.}}$ (100)

TABLE 5 (Continued). EXAMPLE PROBLEM RESULTS - CASE STUDY I
COMPUTED VALUES OF MAJOR PROCESS PARAMETERS
AT VARIOUS MLSS VALUES

PARAMETER	MLSS (mg/l)					Average	Range as percent of average(1)
	1600	1800	2000	2200	2400		
SUB AERFS (cont'd)							
COSTS (¢/1000 gal.)							
AERATOR							
TCOST	1.17	1.06	0.96	0.89	0.83	0.98	34.6
BLOWER							
TCOST	3.88	3.87	3.86	3.85	3.84	3.86	1.0
SLUDGE PUMPS							
COSTO	0.56	0.56	0.56	0.56	0.57	0.56	1.8
ACOST	0.40	0.40	0.41	0.41	0.41	0.41	2.4
TCOST	0.96	0.96	0.97	0.97	0.98	0.97	2.1
FINAL SETTLER							
TCOST	1.32	1.32	1.32	1.32	1.32	1.32	0.0
SUB CHLOR							
BVOL, c.f.	27,829	27,829	27,829	27,829	27,829	27,829	0.0
SUB. THICK							
ATHM, s.f.	4,471	4,038	3,713	3,425	3,194	3,768	33.9
TCOST, ¢/1000 gal.	0.54	0.51	0.49	0.47	0.45	0.49	18.3
Q13, mgd	0.045	0.045	0.046	0.046	0.046	0.046	2.1
TSS13, % solids	5.1	5.1	5.1	5.1	5.1	5.1	0.0

1. $\frac{\text{Max.-Min.}}{\text{Avg.}}$ (100)

TABLE 5 (Continued). EXAMPLE PROBLEM RESULTS - CASE STUDY I
COMPUTED VALUES OF MAJOR PROCESS PARAMETERS
AT VARIOUS MLSS VALUES

PARAMETER	MLSS (mg/l)						Range as percent of
	1600	1800	2000	2200	2400	Average	average(1)
SUB THICK (cont'd)							
Q14, mgd	0.210	0.185	0.167	0.150	0.137	0.170	43.0
TBOD14, lb/day	876	875	879	876	876	876	0.4
TSS14, lb/day	2,095	2,098	2,114	2,113	2,122	2,108	1.3
SUB. VACF							
WP, %	72	72	72	72	72	72	0.0
AVF, s.f.	1,459	1,463	1,468	1,471	1,474	1,467	1.0
TCOST, ¢/1000 gal.	5.60	5.61	5.62	5.63	5.64	5.62	7.1

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1. $\frac{\text{Max.-Min.}}{\text{Avg.}}$ (100)

higher effluent suspended solids values calculated for cases in which lower MLSS values are used.

The calculated flowrate of the principal system recycle stream is extremely dependent on the selected MLSS value, higher flowrates being associated with lower MLSS values. However, the quantity of BOD and suspended solids carried in the stream are relatively unaffected by the selected value of MLSS, indicating that a more dilute recycle stream is produced at lower MLSS values.

The costs calculated for the system are also relatively unaffected by the value selected for MLSS. Amortization (thus capital) costs generally decrease with increasing MLSS values, reflecting a smaller aeration tank volume (Table 5, VAER). Operating costs are calculated to be equal for any selected MLSS value. Due to the slight decrease in amortization costs, total treatment costs are also computed to decrease slightly with increasing values of MLSS.

Output for Processes and Operations

The costs of two processes are not affected by changes in the value of MLSS. These are preliminary treatment and chlorination. This would be expected since neither process is within the system recycle loop, thus should not be affected by the value selected for MLSS.

Primary Settling Tank. The size and performance of the primary settling tanks is slightly affected by changes in the value selected for MLSS, but does not vary in any direct manner with MLSS. The affects of the value selected for MLSS on its cost and performance should be minimal as the impact of various MLSS values is buffered by the sludge-handling system.

Activated Sludge System. The secondary treatment system is affected in a number of major ways by the selected value of MLSS. As would be expected, the required aeration tank volume (VAER) decreases with increasing MLSS values. It is interesting to note that the computed value of VAER is not directly related to the selected value of MLSS, all of the computer values equate to use of a value of approximately 0.56 for F/MLSS, where F is influent BOD. This indicates that kinetics are not affected by the value selected for MLSS, as would be expected within the range of MLSS values selected.

Blower size is related to BOD load (FOOD) and to the mass of active solids carried in the secondary reactor (MLASS), thus it varies slightly and inversely with the value of MLSS selected.

The return sludge flow rate (QR) was computed to be relatively unaffected by selected MLSS values. The reasons for this unexpected result are related to the predicted underflow solids concentration and are discussed in the following paragraphs.

Because the computed value for the area of the final settling tank (AFS) is related to secondary effluent flowrate, the computed value of AFS is not affected by the selected value of MLSS.

The parameter XRSS is the ratio of the concentration of solid material (MLASS, MLBSS, MLDSS, MLISS, MLNBSS) in the settling tank effluent to MLSS, such that:

SS4 = SS * XRSS (1)

where: SS4 = concentration of solids class in system effluent, mg/l

SS = concentration of solids class in aeration tank, mg/l

This factor is used in AERFS to model the performance of the settling tank as a clarifier and is computed using the following emperical equation:

XRSS = 556.1 * GSS ** 0.49421/

XMLSS ** 1.8165/(24.0 * TA) ** 0.4386 (2)

where: GSS = settling tank overflow rate, gpd/sf

TA = aeration tank detention time, days.

This ratio is applied to all classes of solids carried in the system to determine the characteristics of the system effluent.

By inspection of equation 2, it can be seen that XRSS is inversely proportional to MLSS. For this reason, system effluent solids are computed to decrease with increasing values of MLSS. This explains why computed SBOD and TSS values for stream 25 are inversely related to the selected MLSS value.

The computed solids concentration of stream 11 (TSS 11, % solids) is directly proportional to the selected value of MLSS and its computed flow rate (Q11) is inversely proportional. However, the solids content (TSS11, lb/day) of the stream is relatively unaffected by selected MLSS values. The slightly increased solids content of the stream at higher MLSS values is a reflection of predicted enhanced clarification performance of the secondary settling tank (XRSS) at higher MLSS levels.

The predicted changes in the solids concentration of stream 11 were the result of using a fixed value for URSS (DMATX(7,N)).

In subroutine AERFS, the concentration of secondary sludge is directly related to MLSS according to the following equation:

$$TSS11 = XMLSS * URSS \quad (3)$$

where: TSS11 = the suspended solids concentration in stream 11, mg/l

URSS = ratio of solids concentration in the underflow from the final clarifier to aeration tank MLSS.

Thus, changes to the value selected for MLSS will result in changes in the flowrate and solids concentration of the waste sludge stream if the value of URSS is not similarly altered.

The above relationship explains the previously observed lack of variation in return sludge flowrates. Because secondary sludge solids concentration is directly proportional to MLSS in the system as modeled, the return sludge flowrate should be nearly constant, as computed.

The costs computed for the various secondary treatment system components were observed to be related to their computed sizes, as shown in Table 5.

Gravity Thickener. The computed values for the size and cost of the gravity thickener are inversely proportional to selected MLSS values. Because thickener underflow solids concentration (TSS13) was specified as part of the input data (DMATX (2,N)), it is the same in all cases. Since the quantity of solids fed to the thickener (TSS10 and TSS11 in lb/day) are nearly the same for all MLSS values and because the underflow solids concentration is held constant, the flowrate of the thickener underflow stream (Q13) varies only slightly with changes in the value selected for MLSS.

The flowrate of the thickener overflow stream (Q14) varies inversely with selected MLSS values. Since the flowrates of the primary sludge and thickened sludge streams (Q10 and Q13, respectively) are nearly constant, the major cause of this variation observed in secondary sludge flowrate (Q11).

The size of the gravity thickener is computed based on overflow rate (GTH = DMATX (3,N)), or solids loading rate GSTH = DMATX (4,N)), whichever produces the largest surface area. In the cases studied, overflow rate governed due to the low input value selected and computed thickener size varied in proportion to the computed flowrate of stream 12 (the thickener influent stream). This is because the influent (instead of the effluent) flowrate is used in the program as a basis for thickener sizing.

It should be noted that the computed thickener size, cost and performance are a reflection of the input data which was used. If the thickener were actually sized using the data presented in Table 2, it is doubtful that a solids capture of 90 percent and an underflow solids concentration of 5.1 percent would be achievable.

Vacuum Filter. The computed size, cost and performance of the vacuum filter is governed by thickener performance and was computed to vary only slightly with selected MLSS values and in proportion to the computed flow rate of thickened sludge (Q13).

Preliminary Conclusions

It is difficult to evaluate the effect of various MLSS levels on the cost and performance of the system investigated using the above output. Because only the value of MLSS was changed as part of program input, the computed values for secondary sludge solids concentrations varied in direct proportion to the selected MLSS value. This caused the computed values of certain key parameters (Q6, TSS11, TSS20, ATHM, etc.) to differ from what would normally be expected.

Although the thickening performance of the secondary settling tank can be expected to vary with solids loading rate (thus, MLSS concentration), the expected variation within the range of MLSS values investigated should be slight and would most likely be difficult to detect in full-scale operations. The computed results were obtained because the input value for URSS was held constant at 3.75 for all input cases.

Revised Input Data

Because of the above relationship, the value selected for URSS must be reconsidered each time the value selected for MLSS is changed, otherwise secondary sludge solids content may not be modeled as desired. This may be done by estimating an acceptable value for secondary sludge solids concentration (based on experience, the results of pilot studies, etc.), then calculating a new value for URSS using the following equation:

$$URSS = TSS11/XMLSS \qquad (4)$$

To demonstrate the dependence of program results on the value selected for URSS, a second set of five cases was tried. In these cases, both the value of MLSS and the value of URSS were changed. The values used for MLSS in the second set of cases were the same as those used in the first. Using equation 4, new values of URSS were calculated for each MLSS level. In each case, a value of 7,500 mg/l was assumed for TSS11.

The values used for MLSS and URSS in the second set of five cases are shown in Table 6.

TABLE 6. VALUES USED FOR MLSS AND URSS, SECOND SET OF CASES

MLSS, mg/l	URSS
1,600	4.69
1,800	4.17
2,000	3.75
2,200	3.41
2,400	3.12

Revised Output

Output obtained using the revised input shown in Table 6 is summarized in Tables 7 and 8. For comparative purposes, the same parameters listed in Tables 4 and 5 are shown and the same format is used.

By comparison of the results shown in the four tables, those parameters whose value is essentially unaffected by changes in the value selected for URSS were noted. These parameters were:

1. The flow rate and characteristics of streams 10, 13, 24, and 25.
2. The size and cost of the preliminary treatment system; the aeration tank, blowers and final settling tank; and the chlorination system.
3. The size, cost and performance of the vacuum filters.
4. The quantity and characteristics of secondary sludge solids and the quantity of BOD and TSS in the principal recycle stream.
5. The computed values for XRSS.

The major effects of the revised input were in computed values for:

1. Principal recycle (S20), return sludge, and waste sludge (S11) flowrates (Q20,QR, and Q11, respectively).

TABLE 7. EXAMPLE PROBLEM RESULTS - CASE STUDY I COMPUTED VALUES OF MAJOR SYSTEM PARAMETERS AT VARIOUS MLSS AND URSS VALUES

PARAMETER	MLSS(mg/l) - URSS(n.d.)						
	1600, 4.69	1800, 4.17	2000, 3.75	2200, 3.41	2400, 3.12	Average	Range as percent of average(1)
STREAM 24 (Sludge production)							
TSS,%	28	28	28	28	28	28	0.0
TSS, lb/day	18,700	18,700	18,700	18,700	18,700	18,700	0.0
VSS,% TSS	70	70	70	70	70	70	0.0
STREAM 25 (System effluent)							
Q, mgd	9.99	9.99	9.99	9.99	9.99	9.99	0.0
SBOD, mg/l	9.2	8.8	8.4	8.1	7.9	8.5	15.3
DBOD, mg/l	15.8	16.2	16.5	16.8	17.1	16.5	7.9
TBOD, mg/l	25.0	25.0	24.9	24.9	25.0	25.0	0.4
TSS, mg/ l	19.9	19.0	18.2	17.6	17.0	18.3	15.8
STREAM 20 (Principal recycle)							
Q, mgd	0.20	0.20	0.20	0.20	0.20	0.20	0.0
TBOD, lb/day	1,120	1,124	1,126	1,128	1,132	1,126	1.1
TSS, lb/day	2,719	2,729	2,732	2,736	2,739	2,731	0.7
SYSTEM COSTS (¢/1000 gal.)							
TAMM	10.6	10.6	10.5	10.5	10.5	10.5	0.9
TOPER	9.7	9.8	9.8	9.9	10.0	9.8	3.0
TOTAL	20.3	20.4	20.3	20.4	20.5	20.4	1.0

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1. $\frac{\text{Max.-Min.}}{\text{Avg.}}(100)$

TABLE 8. EXAMPLE PROBLEM RESULTS - CASE STUDY I
COMPUTED VALUES OF MAJOR PROCESS PARAMETERS AT VARIOUS MLSS AND URSS VALUES

PARAMETER	MLSS (mg/l), URSS (n.d.)					Average	Range as percent of average(1)
	1600, 4.69	1800, 4.17	2000, 3.75	2200, 3.41	2400, 3.12		
SUB. PREL.							
TCOST (¢/1000 gal.)	1.36	1.36	1.36	1.36	1.36	1.36	0.0
SUB. PRSET							
APS, 1000 s.f.	9.27	9.27	9.28	9.28	9.28	9.28	0.1
PGPM, gpm	304	304	304	304	304	304	0.0
Q4, mgd	10.17	10.17	10.18	10.18	10.18	10.18	0.1
TBOD4, lb/day	14,761	14,761	14,765	14,765	14,767	14,764	0.0
TSS4, lb/day	9,671	9,671	9,674	9,674	9,675	9,673	0.0
Q10, mgd	0.03	0.03	0.03	0.03	0.03	0.03	0.0
TSS10, % solids	4.0	4.0	4.0	4.0	4.0	4.0	0.0
SUB. AERFS							
VAER, mil. gal.	1.97	1.74	1.58	1.43	1.31	1.61	41.0
BSIZE, cfm	8,543	8,523	8,494	8,477	8,456	8,499	1.0
QR, mgd	2.50	2.94	3.42	3.93	4.50	3.46	57.8
AFS, 1000 s.f.	16.0	16.0	16.0	16.0	16.0	16.0	0.0

1. $\frac{\text{Max.-Min.}}{\text{Avg.}}$ (100)

TABLE 8 (Continued). EXAMPLE PROBLEM RESULTS - CASE STUDY I
COMPUTED VALUES OF MAJOR PROCESS PARAMETERS
AT VARIOUS MLSS AND URSS VALUES

PARAMETER	MLSS (mg/l), URSS (n.d.) 1600, 4.69	1800, 4.17	2000, 3.75	2200, 3.41	2400, 3.12	Average	Range as percent of average(1)
SUB AERFS (cont'd)							
XRSS, n.d.	0.0125	0.0106	0.0092	0.0080	0.0071	0.0095	57.0
Q11, mgd	0.181	0.181	0.183	0.183	0.184	0.182	2.0
TSS11, % solids	0.75	0.75	0.75	0.75	0.75	0.75	0.0
TSS11, lb/day	11,291	11,354	11,392	11,419	11,446	11,380	1.4
VSS11, % TSS	78	78	78	78	78	78	0.0
COSTS (¢/1000 gal.)							
AERATOR							
TCOST	1.17	1.06	0.96	0.89	0.83	0.98	34.6
BLOWER							
TCOST	3.88	3.87	3.86	3.86	3.85	3.86	1.0
SLUDGE PUMPS							
COSTO	0.45	0.50	0.56	0.63	0.70	0.57	44.0
ACOST	0.33	0.37	0.41	0.45	0.49	0.41	39.0
TCOST	0.78	0.87	0.97	1.08	1.19	0.98	41.9

1. $\frac{\text{Max.-Min.}}{\text{Avg.}}$ (100)

TABLE 8 (Continued). EXAMPLE PROBLEM RESULTS - CASE STUDY I
COMPUTED VALUES OF MAJOR PROCESS PARAMETERS
AT VARIOUS MLSS AND URSS VALUES

	MLSS (mg/l), URSS (n.d.)						
PARAMETER	1600, 4.69	1800, 4.17	2000, 3.75	2200, 3.41	2400, 3.12	Average	Range as percent of average(1)
SUB AERFS (cont'd)							
FINAL SETTLER							
TCOST	1.32	1.32	1.32	1.32	1.32	1.32	0.0
SUB. CHLOR							
BVOL, c.f.	27,829	27,829	27,829	27,829	27,829	27,829	0.0
SUB. THICK							
ATHM, s.f.	3,674	3,672	3,713	3,717	3,739	3,703	1.8
TCOST (¢/1000 gal.)	0.49	0.49	0.49	0.49	0.49	0.49	0.0
Q13, mgd	0.045	0.046	0.046	0.046	0.046	0.046	2.1
TSS13, % solids	5.1	5.1	5.1	5.1	5.1	5.1	0.0
Q14	0.165	0.164	0.167	0.167	0.168	0.166	2.4
TBOD14, lb/day	872	871	879	879	883	877	1.3
TSS14, lb/day	2,101	2,098	2,114	2,117	2,120	2,110	1.0
SUB. VACF							
WP, %	72	72	72	72	72	72	0.0
AVF, s.f.	1,459	1,464	1,468	1,471	1,474	1,467	1.0
TCOST (¢/1000 gal.)	5.60	5.61	5.62	5.63	5.64	5.62	7.1

1. $\frac{\text{Max.-Min.}}{\text{Avg.}}(100)$

2. Solids concentration of the waste sludge stream (TSS11, % solids).

3. Sludge pumping costs.

4. The cost, performance and size of the gravity thickener.

The differences associated with the values of the above parameters caused the computed size, performance and cost of primary settling tank to be leveled out such that they were found to be unaffected by selected MLSS values.

Overall system costs were affected only slightly by the revised input. However, considerably different trends in total system costs were noted.

Sludge Flow Rates and Pumping Costs. As shown in Figures 2 and 3, the value selected for URSS has a significant effect on the values computed for return and waste sludge flowrates. The original data indicated that the waste sludge flowrate is dependent on the selected value of MLSS and that the return sludge flowrate is only slightly affected. Use of the revised input data produces results which are exactly the opposite. Wasting rates are nearly constant for any MLSS value, and return rates are directly proportional to the selected MLSS value. This is also reflected in sludge pumping costs. Instead of being nearly the same for any MLSS value (Table 5), the revised output indicates that they are directly proportional to the selected value of MLSS (Table 8).

Gravity Thickening. As shown in Figures 4 and 5, results obtained using the original input indicated both gravity thickener size and the expected rate of flow of its overflow stream (Stream 14) were inversely related to MLSS. Results using the revised input indicate that the values of these parameters have very little dependence on the value selected for MLSS. As with the original input, thickener size, cost and performance are a reflection of the input data used.

Total Treatment Costs. Results obtained for total treatment costs using the original and revised data are shown in Figure 6. The results obtained using the original data indicate that total treatment cost will be reduced by increasing the value selected for MLSS, that total operating costs are not affected by the value selected for MLSS; and that capital costs (as reflected in the value of TAMM) will be reduced by increasing MLSS.

The results obtained using the revised input indicate trends which are opposite in all respects to those described above. These results indicate that total treatment costs are generally increased for increased MLSS values; that total

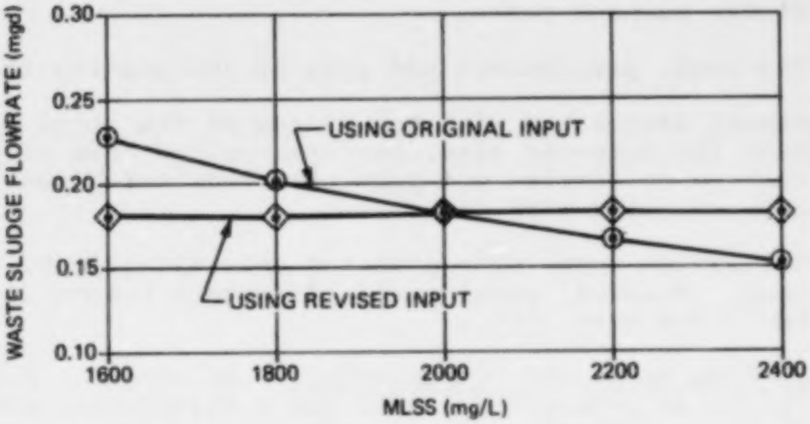

FIG. 2 WASTE ACTIVATED SLUDGE FLOWRATE VS. MLSS – CASE STUDY I

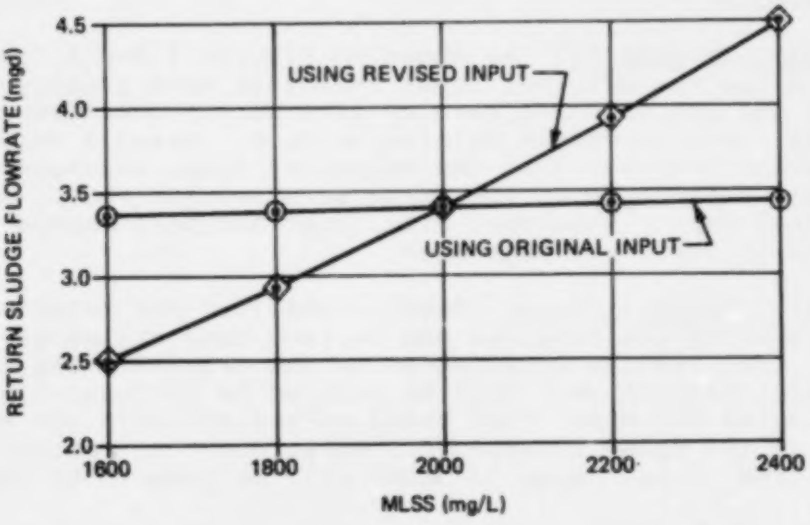

FIG. 3 RETURN SLUDGE FLOWRATE VS. MLSS – CASE STUDY I

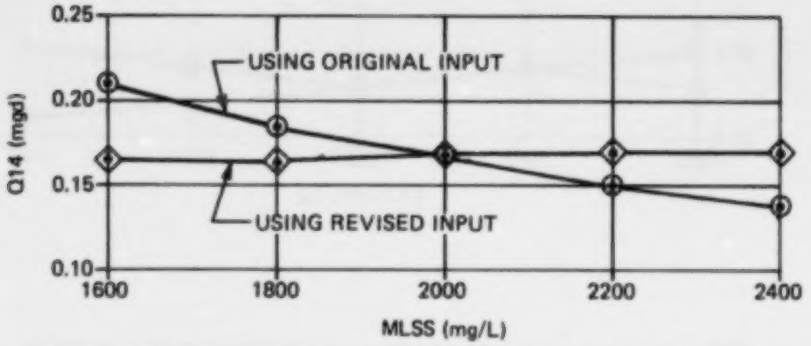

FIG. 4 FLOWRATE OF THICKENER OVERFLOW (Q14) VS. MLSS – CASE STUDY I

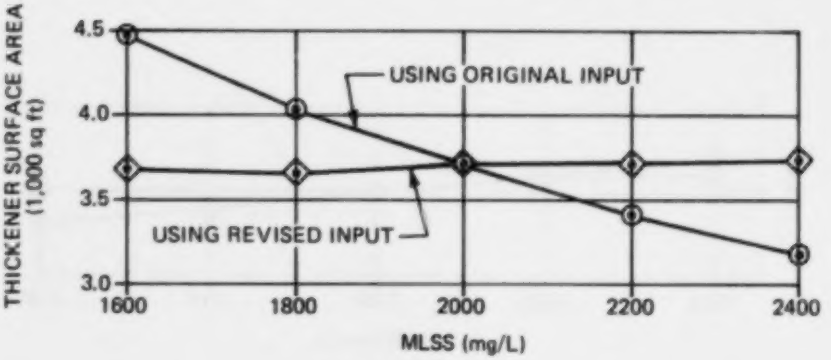

FIG. 5 THICKENER AREA (ATHM) VS. MLSS – CASE STUDY I

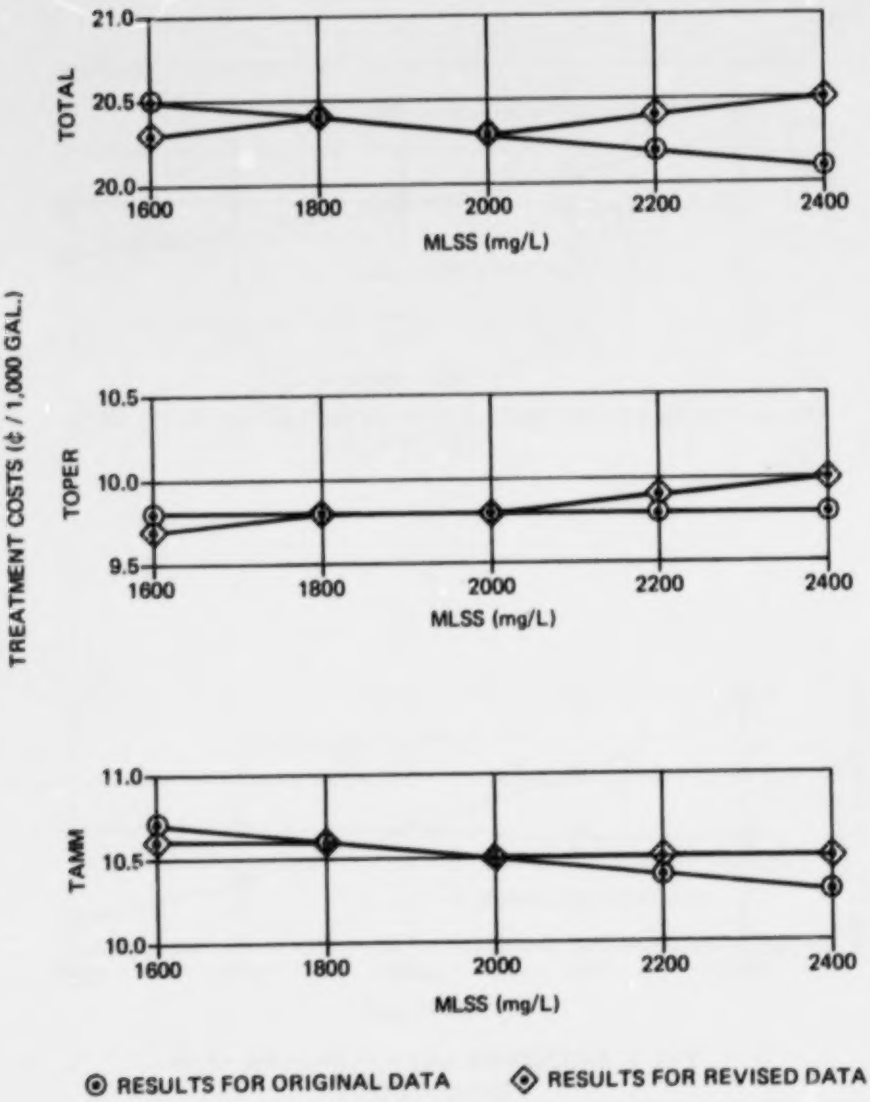

FIG. 6 TOTAL TREATMENT COSTS VS. MLSS – CASE STUDY I

operating costs react similarly; and that capital costs are relatively unaffected.

Two major factors associated with the value selected for URSS combined to cause the opposing results. These factors were:

1. The operating costs associated with return sludge pumping are nearly equal using the original input, using the revised input they increase with increasing MLSS values.
2. The capital costs for gravity thickening were inversely related to selected MLSS values using the original input, using the revised input they are nearly equal.

CONCLUSIONS

A discussion as to the accuracy of the results obtained using the Exec Program is considered beyond the scope of this presentation. Metcalf & Eddy has recently started to analyze the capabilities of the Exec Program and is contemplating a number of revisions which reflect our experience with process performance and cost.

It is the author's opinion that the following conclusions may be drawn from the example problem:

1. That the Exec Program is capable of rapidly performing the detailed computations necessary to evaluate the effects of changing design criteria.
2. That a decision to alter the value selected for a particular design parameter should be checked against its impact on the values assigned to other input parameters.
3. That the results obtained using the Exec Program should be checked to assure that they are reasonable and may be practically achieved. As is the case in using any computer program, the results obtained are only as good as the data provided and the individual who must use them.

RELATED PROBLEMS

Using the basic system and input data described in the example problem, any number of related problems might be considered. The following problems would produce results which may be compared to those obtained as part of the example problem:

1. The effects of correcting thickener sizing and performance parameters.

2. The effects of changing the value of wastewater temperature (DEGC = DMAXT (3,N)).

3. The effects of changing the value of the rate constant used for aeration tank sizing (CAER20 = DMATX (4,N)).

An analagous problem not directly related to the example problem, but which would produce interesting results would be varying the expected primary settling tank suspended solids removal ratio (FRPS = DMATX (1,N)).

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CASE II WORKSHOP

USE OF THE EXEC PROGRAM TO COMPARE THE COST AND PERFORMANCE OF MULTIPLE FLOW SCHEMES

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ABSTRACT

There are many alternative sludge handling methods available for the treatment and disposal of municipal sewage sludge. The Exec Program can be used as a tool by the design engineer to evaluate the cost and performance of alternate sludge handling schemes in order to determine the most cost-effective system. Here, the Exec Program is used to simulate four different sludge handling methods for 1, 10, and 100 mgd plant sizes. The purpose of this exercise is to determine the most economical design for each of the plant sizes under consideration.

INTRODUCTION

The Exec Program cannot be used for extremely detailed design purposes, but it can be a valuable preliminary design tool for the consulting engineer. The performance of many proposed wastewater treatment systems can be simulated along with providing cost estimates for building and operating these plants. The cost data generated by the Exec Program is sufficient for preliminary design purposes. Construction cost (in dollars), amortization cost, operation and maintenance cost, and total treatment cost (all in cents per 1,000 gallons of wastewater treated) are calculated individually for each unit process, and a sum total of each of these costs is given for the entire system. Capital cost is also computed by adding onto construction expenses the costs of yardwork, land, engineering, administration, and interest during construction. All of the cost information can be updated or backdated with respect to time by means of cost indices that are supplied as input to the program. Using the Exec Program, it is possible to optimize a particular treatment system by varying design parameters and noting the effect on performance and cost. Cost-effectiveness studies can be made by comparing alternate treatment systems. Initial studies along these lines are becoming of increasing importance because of the soaring costs of plant construction that are now being experienced.

Several years ago,the Exec Program was used to investigate the potential economic advantages associated with 261 different methods for treating and disposing of sewage sludge. This work is fully described in the article entitled, "Computer Evaluation of Sludge Handling and Disposal Costs" by Robert Smith and Richard G. Eilers, which was published in the Proceedings of the 1975 National Conference on Municipal Sludge Management and Disposal. Sludge production and the costs of constructing and operating each of the various systems were computed. Each system was either primary or activated sludge treatment or both followed by some combination of the following 12 sludge handling processes--lime stabilization, gravity thickening, air flotation thickening, single-stage anaerobic digestion, two-stage anaerobic digestion, aerobic digestion, elutriation, vacuum filtration, centrifugation, sludge drying beds, multiple hearth incineration, and land disposal of liquid sludge. The outcome of the study showed that the cost (in January 1974 dollars per ton of dry solids processed) for treating and disposing of sewage sludge ranges from about $30 per ton for anaerobic digestion followed by dewatering on sand drying beds to over $100 per ton when the sludge is dewatered by vacuum filtration or centrifugation and then incinerated. Treatment and disposal of sludges produced in municipal wastewater treatment plants were shown to account for as much as 60 percent or as little as 20 percent of the total cost of treatment. Therefore, careful consideration should be given to selecting the sludge handling method which meets the site-specific constraints at a minimum cost. The Exec Program, which is capable of examining the cost and performance of a wide variety of alternative sludge handling schemes, can be used as a management tool to narrow the range of options when design conditions are known.

The example problem and the assigned problem for this workshop will combine to be a greatly simplified application of the study just described. Instead of 261 different methods for sludge handling, only four will be considered. These four systems will, however, make use of most of the unit processes that were used in the large study.

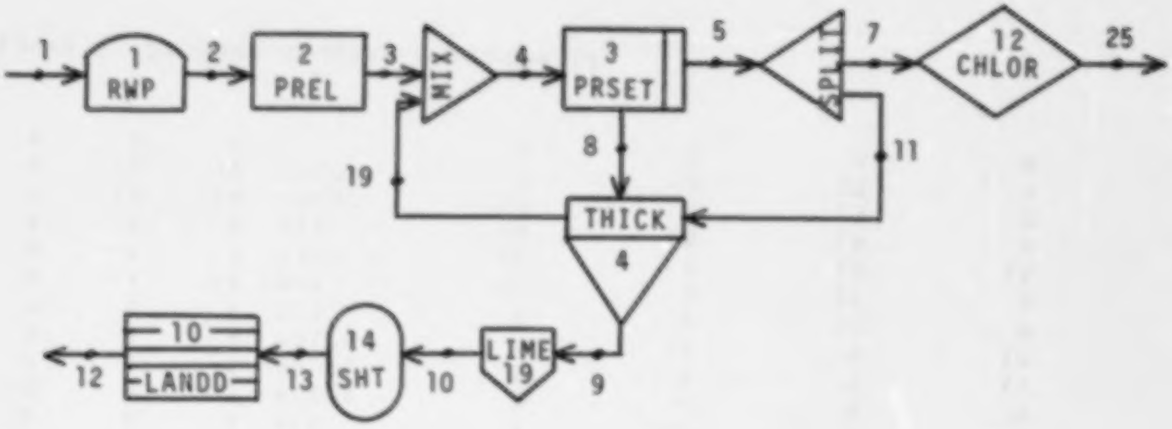
This exercise will examine four different sludge handling schemes for 1, 10, and 100 mgd size plants. The object of the study will be to determine the most economical design for the various plant sizes under consideration. The liquid handling phase of each of the four designs will be the same and consist of the following unit processes: raw wastewater pumping (RWP), preliminary treatment (PREL), primary sedimentation (PRSET), and chlorination (CHLOR). The sludge handling phase of the four designs will be as follows: System (1) - gravity thickening (THICK), lime stabilization (LIME), sludge holding tanks (SHT), and land disposal of liquid sludge (LANDD); System (2) - gravity thickening (THICK), anaerobic digestion (DIG), sludge holding tanks (SHT), vacuum filtration (VACF), and multiple hearth incineration; System (3) - gravity thickening (THICK), anaerobic digestion (DIG), sludge holding tanks (SHT), centrifugation (CENT), and multiple hearth incineration (MHINC); System (4) - gravity thickening (THICK), anaerobic digestion (DIG), and sand drying beds (SBEDS). It will also be necessary to use the stream mixer (MIX) and stream splitter (SPLIT) processes in drawing up the system configurations.

In solving the problem it will not be necessary to modify or augment any of the existing subroutines in the Exec Program. The user will be required to draw up his own system configuration and prepare all necessary input data to simulate his design on the Exec Program.

EXAMPLE PROBLEM

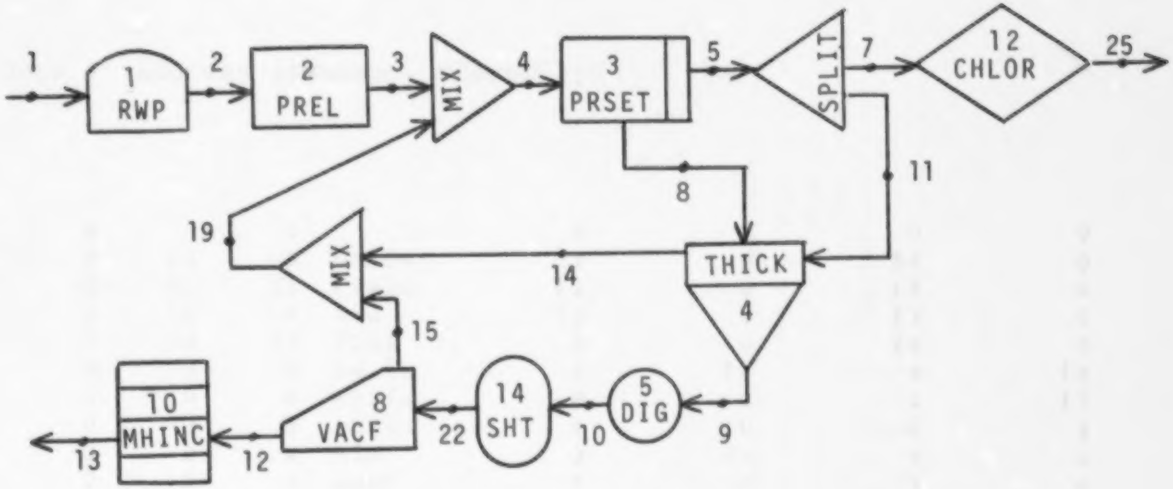
In order to give guidance to those participants that are relatively unfamiliar with computer applications work or the Exec Program itself, System (1), (2), and (3) will be solved in detailed by the lecturer. In doing this, it will not be necessary to change any input or output requirements, nor will any program modification be necessary.

Figures 1, 2, and 3 give the process diagrams for Systems (1), (2), and (3). Arbitrary stream numbers and process numbers have been assigned as indicated on the diagrams. The influent


1
1
RWP
2
2
PREL
3
MIX
4
3
PRSET
5
SPLIT
7
12
CHLOR
25
8
19
11
THICK
4
LIME
19
9
14
SHT
10
10
LANDD
13
12

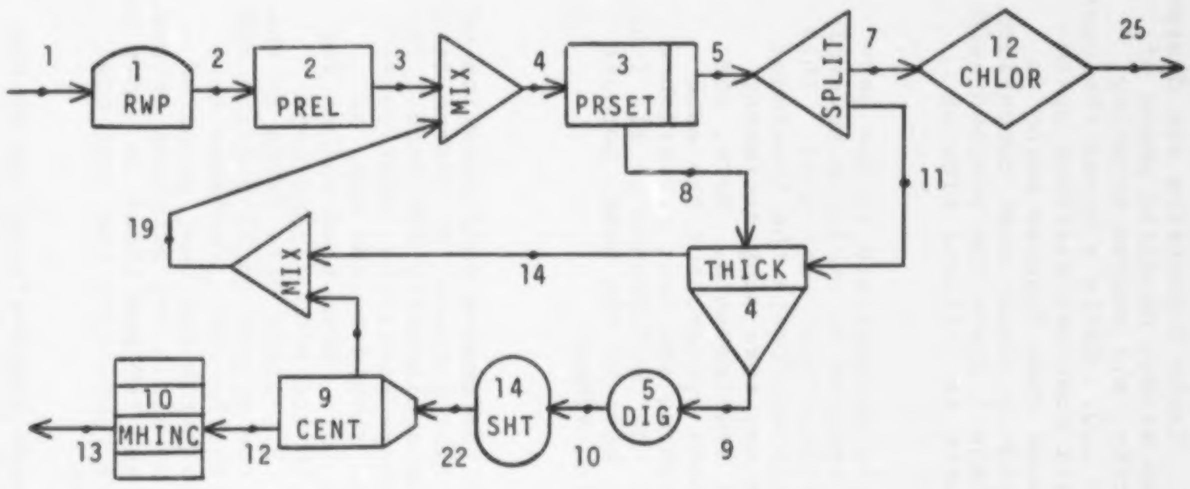
K	N	PROCESS		IS1	IS2	OS1	OS2
0	1	15	RWP	1	0	2	0
0	2	1	PREL	2	0	3	0
0	0	4	MIX	3	19	4	0
0	3	2	PRSET	4	0	5	8
0	0	5	SPLIT	5	0	7	11
0	4	8	THICK	8	11	9	19
0	19	23	LIME	9	0	10	0
0	14	16	SHT	10	0	13	0
0	10	22	LANDD	13	0	12	0
0	12	12	CHLOR	7	0	25	0
9	0	0		0	0	0	0

Figure 1 Process diagram - system (1)


1
1
RWP
2
2
PREL
3
MIX
4
3
PRSET
5
SPLIT
7
12
CHLOR
25
8
11
19
MIX
14
THICK
4
15
10
MHINC
13
12
8
VACF
22
14
SHT
10
5
DIG
9

K	N	PROCESS	IS1	IS2	OS1	OS2
0	1	15 RWP	1	0	2	0
0	2	1 PREL	2	0	3	0
0	0	4 MIX	3	19	4	0
0	3	2 PRSET	4	0	5	8
0	0	5 SPLIT	5	0	7	11
0	4	8 THICK	8	11	9	14
0	5	6 DIG	9	0	10	0
0	14	16 SHT	10	0	22	0
0	8	7 VACF	22	0	12	15
0	0	4 MIX	14	15	19	0
0	10	14 MHINC	12	0	13	0
0	12	12 CHLOR	7	0	25	0
9	0	0	0	0	0	0

Figure 2 Process diagram - system (2)


1
1
RWP
2
2
PREL
3
MIX
4
3
PRSET
5
SPLIT
7
12
CHLOR
25
8
11
19
MIX
14
THICK
4
10
MHINC
13
12
9
CENT
22
14
SHT
10
5
DIG
9

K	N	PROCESS	IS1	IS2	OS1	OS2
0	1	15 RWP	1	0	2	0
0	2	1 PREL	2	0	3	0
0	0	4 MIX	3	19	4	0
0	3	2 PRSET	4	0	5	8
0	0	5 SPLIT	5	0	7	11
0	4	8 THICK	8	11	9	14
0	5	6 DIG	9	0	10	0
0	14	16 SHT	10	0	22	0
0	9	17 CENT	22	0	12	15
0	0	4 MIX	14	15	19	0
0	10	14 MHINC	12	0	13	0
0	12	12 CHLOR	7	0	25	0
9	0	0	0	0	0	0

Figure 3 Process diagram - system (3)

stream vector, containing the flow and contaminant concentrations that are to be used, is listed in Table 1. The design variables (DMATX input) for the liquid handling phase of each system are given in Table 2. These will be the same for each of the four systems being investigated. Table 3 contains the design variables that are to be used for the sludge handling phase of each system. Note that, for simplicity, all excess capacity factors (ECF) have been set equal to 1.0. Table 4 gives the cost inputs that are necessary to bring all cost calculations up-to-date. This will result in all computed cost figures being in March 1977 dollars, and thereby provide a timely cost comparison of the four alternative systems. Table 5 lists the punched card data for Systems (1), (2), and (3) with an influent flow of 1 mgd.

The purpose of this case study is to indicate to the participants how they can use the Exec Program to evaluate several alternate design solutions for a specific treatment goal. This is the type of problem that frequently confronts the treatment plant designer, although the problem may take many different forms and specify different kinds of requirements. Here, the problem is to determine the lowest cost system, but the same type of analysis can be used to determine the best performance system where appropriate. Note that the performance of all four of these systems under consideration will be the same, because each one uses the same liquid handling scheme.

ASSIGNED PROBLEM

The participants are to draw up the system configuration of unit processes along with all connecting streams for System (4). The process and stream numbers may be arbitrarily assigned. Input values for the influent stream characteristics, cost constants, and process decision variables should be the same as those used for Systems (1), (2), and (3). Note that values for the decision variables associated with the sand drying beds unit process are also given in Table 3. Input data cards to the program should be prepared based on the system configuration and the decision variables associated with the unit processes that are to be used. Once the set of data cards has been prepared and double checked to eliminate any possible key punching errors, the program should be run at 1, 10, and 100 mgd flows in order to generate the desired costs for use in completing the cost comparison of the four alternate systems.

After all the test cases have been successfully run on the Exec Program, the total treatment cost (cents per 1,000 gallons, March 1977 dollars) of the four systems should be as follows:

Table 1

INFLUENT STREAM VECTOR

FORTRAN Variable Name		Parameter Definition	Influent Value
SMATX(1,I)	I	stream number	-
SMATX(2,I)	Q	volume flow, mgd	1., 10., 100.
SMATX(3,I)	SOC	solid organic carbon, mg/l	105.
SMATX(4,I)	SNBC	solid nonbiodegradable carbon, mg/l	30.
SMATX(5,I)	SON	solid organic nitrogen, mg/l	10.
SMATX(6,I)	SOP	solid organic phosphorus, mg/l	2.
SMATX(7,I)	SFM	solid fixed matter, mg/l	30.
SMATX(8,I)	SBOD	solid 5-day BOD, mg/l	140.
SMATX(9,I)	VSS	volatile suspended solids, mg/l	224.
SMATX(10,I)	TSS	total suspended solids, mg/l	254
SMATX(11,I)	DOC	dissolved organic carbon, mg/l	43.
SMATX(12,I)	DNBC	dissolved nonbiodegradable carbon, mg/l	11.
SMATX(13,I)	DN	dissolved nitrogen, mg/l	19.
SMATX(14,I)	DP	dissolved phosphorus, mg/l	4.
SMATX(15,I)	DFM	dissolved fixed matter, mg/l	500.
SMATX(16,I)	ALK	alkalinity, mg/l	250.
SMATX(17,I)	DBOD	dissolved 5-day BOD, mg/l	60.
SMATX(18,I)	NH3	ammonia nitrogen as N, mg/l	15.
SMATX(19,I)	NO3	nitrate as N, mg/l	0.

Table 2

LIQUID HANDLING PHASE

DESIGN VARIABLES

Raw Wastewater Pumping (RWP)		
DMATX(1,N)	HEAD	30.
DMATX(16,N)	ECF	1.
Preliminary Treatment (PREL)		
DMATX(1,N)	IPREL	1.
DMATX(16,N)	ECF	1.
Primary Sedimentation (PRSET)		
DMATX(1,N)	FRPS	.5
DMATX(2,N)	URPS	400.
DMATX(3,N)	HPWK	14.
DMATX(15,N)	ECF	1.
DMATX(16,N)	ECF	1.
Chlorination-Dechlorination (CHLOR)		
DMATX(1,N)	DCL2	8.
DMATX(2,N)	TCL2	30.
DMATX(3,N)	CCL2	220.
DMATX(4,N)	DSO2	2.5
DMATX(5,N)	CSO2	180.
DMATX(14,N)	ECF	1.
DMATX(15,N)	ECF	1.
DMATX(16,N)	ECF	1.

Table 3

SLUDGE HANDLING PHASE

DESIGN VARIABLES

Gravity Thickening (THICK)

DMATX(1,N)	TRR	.95
DMATX(2,N)	TSS	50,000.
DMATX(3,N)	GTH	700.
DMATX(4,N)	GSTH	8.
DMATX(16,N)	ECF	1.

Lime Addition to Sludge (LIME)

DMATX(1,N)	DLIME	200.
DMATX(2,N)	CLIME	25.
DMATX(16,N)	ECF	1.

Sludge Holding Tanks (SHT)

DMATX(1,N)	TD	15.
DMATX(16,N)	ECF	1.

Land Disposal of Liquid Sludge (LANDD)

DMATX(1,N)	TAYR	15.
DMATX(2,N)	SP	.25
DMATX(3,N)	DISP	10.
DMATX(4,N)	TS	1200.
DMATX(5,N)	YRSL	6.
DMATX(15,N)	ECF	1.
DMATX(16,N)	ECF	1.

Single Stage Anaerobic Digestion (DIG)

DMATX(1,N)	TC	15.
DMATX(2,N)	TCIG	30.
DMATX(16,N)	ECF	1.

Sand Drying Beds (SBEDS)

DMATX(1,N)	SOUT	.35
DMATX(2,N)	TSS	50.
DMATX(16,N)	ECF	1.

Vacuum Filtration (VACF)

DMATX(1,N)	VFL	4.9
DMATX(2,N)	HPWK	35.
DMATX(3,N)	TSS	200.
DMATX(4,N)	IVACF	1.
DMATX(5,N)	FECL3	42.
DMATX(6,N)	CAO	0.
DMATX(7,N)	CFECL	.064
DMATX(8,N)	CCAO	.0125
DMATX(9,N)	DPOLY	0.
DMATX(10,N)	CPOLY	.33
DMATX(16,N)	ECF	1.

Multiple Hearth Incineration (MHINC)

DMATX(1,N)	ML	2.
DMATX(2,N)	NINC	1.
DMATX(3,N)	HPWK	35.
DMATX(4,N)	SPER	5.
DMATX(5,N)	WV	0.
DMATX(6,N)	HV	10,000.
DMATX(7,N)	TYPE	1.
DMATX(8,N)	FC	.30
DMATX(9,N)	CNG	.97
DMATX(16,N)	ECF	1.

Centrifugation (CENT)

DMATX(1,N)	CRR	.95
DMATX(2,N)	TSS	200,000.
DMATX(3,N)	HPWK	35.
DMATX(4,N)	XCEN	1.
DMATX(5,N)	POLY	2.
DMATX(6,N)	CPOLY	2.
DMATX(7,N)	GPMN	100.
DMATX(8,N)	CNMIN	2.
DMATX(16,N)	ECF	1.

Table 4

DESIGN VARIABLES FOR COSTS

Cost Input

DMATX(1,20)	CCI	2.709
DMATX(2,20)	WPI	1.916
DMATX(3,20)	RI	.06
DMATX(4,20)	YRS	25.
DMATX(5,20)	DHR	5.65
DMATX) 6,20)	PCT	.15
DMATX(7,20)	DA	2000.
DMATX(8,20)	CCINT	.06
DMATX(9,20)	XLAB	0.
DMATX(10,20)	CKWH	.03

```
PRIMARY TREATMENT PLANT     1 MGD     THICK/DIG/SHT/CENT/MHINC     MARCH 1977 $$$
        1.      105.       30.       10.        2.       30.      140.      224.
      254.       43.       11.       19.        4.      500.      250.       60.
       15.        0.
     2.709     1.916       .06       25.      5.65       .15     2000.       .06
        0.       .03
 0  1  15 RWP       1         0         2         0
       30.
                                                                              1.
 0  2   1 PREL      2         0         3         0
        1.
                                                                              1.
 0  0   4 MIX       3        19         4         0
 0  3   2 PRSET     4         0         5         8
        .5      400.       14.
                                                                    1.        1.
 0  0   5 SPLIT     5         0         7        11
 0  4   8 THICK     8        11         9        14
       .95    50000.      700.        8.
                                                                              1.
 0  5   6 DIG       9         0        10         0
       15.       30.
                                                                              1.
 0 14  16 SHT      10         0        22         0
       15.
                                                                              1.
 0  9  17 CENT     22         0        12        15
       .95   200000.       35.        1.        2.        2.      100.        2.
                                                                              1.
 0  0   4 MIX      14        15        19         0
 0 10  14 MHINC    12         0        13         0
        2.        1.       35.        5.        0.    10000.        1.       .30
       .97                                                                    1.
 0 12  12 CHLOR     7         0        25         0
        8.       30.      220.       2.5      180.
                                                          1.        1.        1.
 9
```

Table 5 (continued) - System (3)

```
PRIMARY TREATMENT PLANT      1 MGD     THICK/DIG/SHT/VACF/MHINC     MARCH 1977 SSS
        1.      105.       30.       10.        2.       30.      140.      724.
      254.       43.       11.       19.        4.      500.      250.       60.
       15.        0.
     2.709     1.916       .06       25.      5.65       .15     2000.       .06
        0.       .03
0  1  15 RWP        1         0         2         0
       30.
                                                                              1.
0  2   1 PREL       2         0         3         0
        1.
                                                                              1.
0  0   4 MIX        3        19         4         0
0  3   2 PRSET      4         0         5         8
        .5      400.       14.
                                                                    1.        1.
0  0   5 SPLIT      5         0         7        11
0  4   8 THICK      8        11         9        14
       .95    50000.      700.        8.
                                                                              1.
0  5   6 DIG        9         0        10         0
       15.       30.
                                                                              1.
0 14  16 SHT       10         0        22         0
       15.
                                                                              1.
0  8   7 VACF      22         0        12        15
       4.9       35.      700.        1.       42.        0.      .064     .0125
        0.       .33                                                          1.
0  0   4 MIX       14        15        19         0
0 10  14 MHINC     12         0        13         0
        2.        1.       35.        5.        0.    10000.        1.       .30
       .97                                                                    1.
0 12  12 CHLOR      7         0        25         0
        8.       30.      220.       2.5      180.
                                                            1.        1.        1.
9
```

Table 5 (continued) - System (2)

```
 4
PRIMARY TREATMENT PLANT     1 MGD     THICK/LIME/SHT/LANDD      MARCH 1977 888
        1.      105.       30.       10.        2.       30.      140.      224.
      254.       43.       11.       19.        4.      500.      250.       60.
       15.        0.
     2.709     1.916       .06       25.      5.65       .15     2000.       .06
        0.       .03
0  1  15 RWP        1         0         2         0
       30.
                                                                             1.
0  2   1 PREL       2         0         3         0
        1.
                                                                             1.
0  0   4 MIX        3        19         4         0
0  3   2 PRSET      4         0         5         8
        .5      400.       14.
                                                                   1.        1.
0  0   5 SPLIT      5         0         7        11
0  4   8 THICK      8        11         9        19
       .95    50000.      700.        8.
                                                                             1.
0 19  23 LIME       9         0        10         0
      200.       25.
                                                                             1.
0 14  16 SHT       10         0        13         0
       15.
                                                                             1.
0 10  22 LANDD     13         0        12         0
       15.       .25       10.     1200.        6.
                                                                   1.        1.
0 12  12 CHLOR      7         0        25         0
        8.       30.      220.       2.5      180.
                                                         1.        1.        1.
9
```

Table 5 Punched Card Data - System (1)

Size, mgd	System (1)	System (2)	System (3)	System (4)
1	38.1	55.9	62.8	39.8
10	15.0	18.3	17.5	12.9
100	9.7	10.2	8.7	8.1

Complete summary costs for the four systems are listed in Table 6. These costs are taken from the cost summary page (the last page) of the computer printouts for each system. From this analysis, it can be seen that System (1) is the lowest in cost at 1 mgd, and System (4) is the lowest in cost at 10 and 100 mgd. However, System (3) is very competitive at the 100 mgd level. In practice, Systems (2) and (3) are usually much more desirable for larger plants, since Systems (1) and (4) require considerable land areas for plants larger than 10 mgd. Quite often, convenient large land parcels are simply not available, especially in metropolitan areas. For various reasons, such as this one, it is not always possible to choose the least cost solution even when it can be accurately determined.

The outcome of this analysis can, of course, be greatly altered by changing some of the various decision variables associated with the sludge handling processes. However, based on the assumptions that were made, the cost figures that have been calculated can be assumed to be useful enough for preliminary design applications. This type of information is of considerable value to the planner when he is evaluating several options for solving a specific problem. The principal deterrents to better system design are usually the manual effort required in computing the cost and performance of alternative designs and the labor required to accumulate and correlate the large amount of experimental process design data which is often available. With the Exec Program, the process designer has within his grasp a tool for quantitatively selecting the most cost-effective system of processes to achieve a desired treatment goal. Analysis of this type leads to obtaining better treatment at a minimum cost.

Table 6

TOTAL PLANT COSTS

	Plant Size		
	1 mgd	10 mgd	100 mgd
System (1):			
Total Capital Cost, $	792,964	2,758,343	14,047,269
Total Amortization Cost, ¢/1,000 gallons	17.521	6.116	3.193
Total O&M Cost, ¢/1,000 gallons	20.611	8.851	6.496
Total Treatment Cost, ¢/1000 gallons	38.132	14.966	9.689
System (2):			
Total Capital Cost, $	1,546,321	5,113,099	27,346,522
Total Amortization Cost, ¢/1,000 gallons	33.141	10.958	5.861
Total O&M Cost, ¢/1,000 gallons	22.784	7.388	4.358
Total Treatment Cost, ¢/1,000 gallons	55.924	18.347	10.219
System (3):			
Total Capital Cost, $	1,566,541	4,258,936	19,163,204
Total Amortization Cost, ¢/1,000 gallons	39.668	10.196	4.371
Total O&M Cost, ¢/1,000 gallons	23.103	7.340	4.338
Total Treatment Cost, ¢/1,000 gallons	62.771	17.536	8.708
System (4):			
Total Capital Cost, $	1,024,567	3,175,571	18,360,488
Total Amortization Cost, ¢/1,000 gallons	21.959	6.806	3.935
Total O&M Cost, ¢/1,000 gallons	17.846	6.058	4.195
Total Treatment Cost, ¢/1,000 gallons	39.805	12.863	8.130

CASE III WORKSHOP:

USE OF THE EXEC PROGRAM TO DETERMINE THE EFFECT OF ECONOMIC PARAMETERS ON CAPITAL AND O/M COSTS FOR A GIVEN FACILITY DESIGN

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ABSTRACT

An integral part of the Executive Digital Computer Program for Preliminary Design of Wastewater Treatment Systems is the determination of capital, amortization and operation and maintenance costs. The costs calculated for a given facility are based on various relationships contained in the COST and individual process subroutines. The costs data inputs and outputs are discussed according to explicit, implicit or omitted relationships within the program. Information is presented to aid in the selection and evaluation of these costs data. An illustrative problem is included to demonstrate the effects of costs data on the proper use of the program.

INTRODUCTION

The majority of users of the Executive Digital Computer Program are interested in the program's capabilities to generate cost data. The cost figures may be used in Facilities Planning by consulting engineers, planners, and regulatory agencies to determine the most cost-effective wastewater management alternative. The operation and maintenance costs data may be used by operating personnel and designers to compare either existing or projected costs with typical values. Individual process costs may be evaluated in order to determine the most cost sensitive unit processes and may indicate where redesign or a change in operating parameters is warranted.

Utilization of the program for costs data requires however, a knowledge of the costs functions and a judicious selection of data input values. The cost functions contained in the program are either explicit or implicit depending on the process or cost subroutine. The cost functions were developed based on actual construction or operation and maintenance costs correlated to some design or operation parameter(s). The cost functions were further optimized to reflect variations in local conditions, cost indices, labor rates and material costs, etc.

EXPLICIT COST CONSIDERATIONS

Primarily, the cost considerations within the Exec Program are explicit. Therefore, either in the COST subroutine or the individual process subroutines, data input values are required to generate costs.

The COST subroutine contains the majority of the explicit cost considerations. The individual cost data required are made part of the program as data inputs to a decision matrix (DMATX). A total of ten (10) inputs parameters to the COST subroutine are required. These inputs are discussed below:

> DMATX(1,20),CCI- In order to account for the variations of construction cost with time, the sewage treatment plant construction cost index value is required. The historical value however is trended to reflect a national average. Recently the USEPA has started to publish values for twenty (20) cities in order to correct for variations in regional construction costs. In the COST subroutine the CCI value is first ratioed to the base value of 1957-59. Then this ratio is multiplied times the capital costs calculated for each process to update the costs to the time reference of the input value. For printout purposes, the ratio is then multiplied by the base value and the original input value is printed in the costs display.

DMATX(2,20),WPI- The wholesale price index for industrial commodities is required to account for the cost variations of materials and supplies used in operation and maintenance. Again a base of 1957-59 is used. The value is ratioed to the base value and the ratio multiplied times the calculated operation and maintenance costs.

DMATX(3,20), RI- In order to project amortized costs, the amortization interest rate is fed into the program, expressed as a fraction. In accordance with the guidelines for Facilities Planning the rate as issued periodically by the Water Resources Council in the Federal Register should be used. The rate is internally used in the COST subroutine to calculate the amortization factor which is subsequently used to generate amortized costs for each unit process.

DMATX(4,20),YRS- An amortization period, expressed in years, is required to generate amortized costs. In Facilities Planning the period is generally not less than twenty(20) years.

DMATX(5,20), DHR- The wastewater treatment plant personnel hourly wage rate is required as an input value. The wage is expressed as $/hr. This value fluctuates with region and is typically around $5. This value is used to calculate operation and maintenance costs for each unit process.

DMATX(6,20), PCT- The fraction of direct labor costs that is charged as indirect labor cost is required to determine actual total labor cost. Typically this value is approximately 0.2 to 0.3 depending on the location and labor contracts. This value is used to adjust the operation and maintenance costs.

DMATX(7,20), DA- The program calculates the amount of land required for a given treatment facility. The total costs for the plant include the cost of the required land. The cost of land represented as $/acre is made a data input. Typically this value is $1,500/acre. Extreme variations in this value are quite common depending on the locality. The cost does not include any improvements.

DMATX(8,20), CCINT- The interest rate during construction, expressed as a fraction, is required to calculate total capital costs. This value is used to calculate the cost of borrowed capital to finance the total capital cost, yardwork, land, engineering, legal and administrative expenses during the construction period. This value currently runs between 0.08 to 0.12.

DMATX(9,20), XLAB- The COST subroutine contains an equation to calculate the cost of maintaining a laboratory facility as a function of the treatment plant capacity. A value of 1.0 is used for activated sludge plants or a value of zero is used for primary or trickling filter plants.

DMATX(10,20), CKWH- The cost of electrical power expressed as $/kilowatt hour is a required data input to calculate operation and maintenance costs. Typical values run between $0.01 to $0.04 depending on the locality.

The above ten(10)data inputs to the cost subroutine are used to calculate the components of total capital, amortized and operation and maintenance costs. These cost figures are displayed as a part of the output (OMATX). A total of sixteen(16) output parameters are generated by the COST subroutines. The program user should have some knowledge of the means used to calculate the output values in order to assess the validity of the output. These outputs are discussed below:

OMATX(1,20), RATIO- The multiplier used to factor into individual unit processes construction costs for yardwork, land, engineering, legal and fiscal, and interest during construction is printed as a ratio. This value should be between 1.25 and 1.45.

OMATX(2,20), TCAP- This number is the total capital cost of the entire treatment system excluding yardwork, land, engineering, legal, fiscal and interest during construction. This value is expressed in dollars.

OMATX(3,20), YARD- The total capital cost of yardwork expressed in dollars. This value is calculated as 14 percent of the TCAP.

OMATX(4,20), TCC- Subtotal of TCAP and YARD expressed in dollars.

OMATX(5,20), XLAND- The cost of land required for the treatment plant. The value is a function of land cost and plant flow.

OMATX(6,20), ENG- The cost of engineering services for plant construction is expressed in dollars. It is calculated as a decreasing function of the TCC.

OMATX(7,20), SUBT1- The subtotal of TCAP + YARD + XLAND + ENG expressed in dollars.

OMATX(8,20), FISC- The cost of legal, fiscal and administrative services during construction is expressed in dollars. This cost is calculated as a decreasing function of

SUBT1.

OMATX(9,20), SUBT2- The subtotal of SUBT1 and FISC is expressed in dollars.

OMATX(10,20), XINT- The cost of interest during construction is displayed in dollars. It is calculated as a function of SUBT2.

OMATX(11,20), ACRE- This value is the total land requirement for the plant, in acres.

OMAXTX(12,20), AF- This amortization factor is used in calculating amortized costs. The value should be between 0.07 and 0.12.

OMATX(17,20), TOT- The total capital cost of the entire plant is presented in dollars. This represents the sum of SUBT2 and XINT.

OMATX(18,20), TAMM- The total amortization cost of the entire system, in cents per 1,000 gallons is represented by this value.

OMATX(19,20), TOPER- The total operation and maintenance cost of the entire system, in cents per 1000 gallons.

OMATX(20,20), TOTAL- The total treatment cost (TAMM + TOPER) of the entire system, in cents per 1000 gallons.

The remaining explicit cost considerations within the Exec Program are required data inputs in the process subroutines. Examples include:

VACF - DMATX(7,N), CFE- The cost of adding iron, expressed in dollars per pound. Typical values run approximately 0.1.

VACF - DMATX(8,N), CCAO- The cost of adding alum, expressed in dollars per pound. An approximate value is 0.2.

TFLOT - DMATX(7,N), CPOLY- The cost of polymer, in dollars per pound. A typical value is 1.0.

MHINC - DMATX(8,N), FL- The cost of fuel oil in dollars per gallon. A typical value is 0.45.

MHINC - DMATX(9,N), CNG- The cost of natural gas in dollars per 1000 cubic feet. A typical value is 2.50.

IMPLICIT COST CONSIDERATIONS

Within the various process subroutines are a few subtle cost considerations which can drastically affect the treatment facility costs. These implicit cost considerations present the greatest drawback in using the Exec Program. If the user is unaware of their importance and selects the values in a haphazard manner, the costs data are meaningless.

The excess capacity factor (ECF) is of extreme importance in using the Exec Program for cost estimating. In most cases, the cost equation is a function of some process parameter multiplied by the ECF. An accurate value for the ECF is a requirement for valid output data. Although Eilers and Smith do not elaborate on the use of the ECF, the following should provide the program user with sufficient data to more accurately assign a value to ECF in each individual unit process subroutine. It is to be noted that the cost equations for operating and maintenance do not include the ECF.

RWP, CCOST = f (AP * ECF);
where $QP = 1.78 * Q_{IS1} ** 0.92$

PREL, CCOST = f $(Q_{IS1} * ECF)$

PRSET, CCOST = f (APS); settler

$$APS = ((\frac{Q_{IS1} * 1000.}{GPS}) * ECF)$$

PRESET, CCOST = f (PGPM); sludge pumps

$$PGPM = ((\frac{Q_{OS2} * 116,666.7}{HPWK}) * ECF)$$

AERFS, CCOST = f (VAER); aerator

VAER = f (ECF)

AERFS, CCOST = f (BSIZE): blower

BSIZE = f (ARCFD * ECF)

AERFS, CCOST = f (QR); sludge pumps

QR includes ECF

AERFS, CCOST = f (AFS); final settler

$$AFS = ((\frac{Q_{SO1} * 1000}{GSS}) * ECF)$$

FACF, CCOST = f (AVF);

$$AVF = \left(\frac{TSS_{IS1} * Q_{IS1} * 58.13}{FVF * HPWK}\right) * ECF$$

THICK, CCOST = f (ATHM);

$$ATHM = \left(\frac{Q_{OS2} * Q_{OS1}}{GTH}\right) * 10^6 * ECF$$

ELUT, CCOST = f (AE);

AE includes ECF

TRFS, CCOST = f (VOL); filter

VOL = FAREA * DEPTH * ECF

TRFS, CCOST = f (AFS); final settler

$$AFS = \left(\frac{Q_{IS1} * 1000}{GSS}\right) * ECF$$

TRFS, CCOST = f (Q_{IS1} * 1.5 * ECF); sludge pumps

CHLOR, CCOST = f (Q_{IS1} * DCL2 * 8.33 * ECF); feed system

CHLOR, CCOST = f $\left(\frac{Q_{IS1} * TCL2}{1.44 * 7.48} * ECF\right)$; contact basin

SHT, CCOST = f (VSHT);

$$VSHT = \frac{QP * TD * 1000}{7.48} * ECF$$

SLP, CCOST = f (QP * ECF)

The other implicit cost considerations include the use of QP, PGPM and HPWK. The QP value represents peak flow. This value is used in various subroutines to calculate cost data. QP is calculated as 1.78 times Q raised to the 0.92 power. This value may not represent the actual design condition and generate erroneous data. The PGPM input is used to establish the firm pumping capacity in various subroutines. The program user should be aware of the actual firm pumping capacity required and the associated costs, both of which are influenced by the ECF. The HPWK input is the hours per week that the sludge pumps are operated. If too low a value is selected by the user, the pumping capacity and costs will be inordinately high.

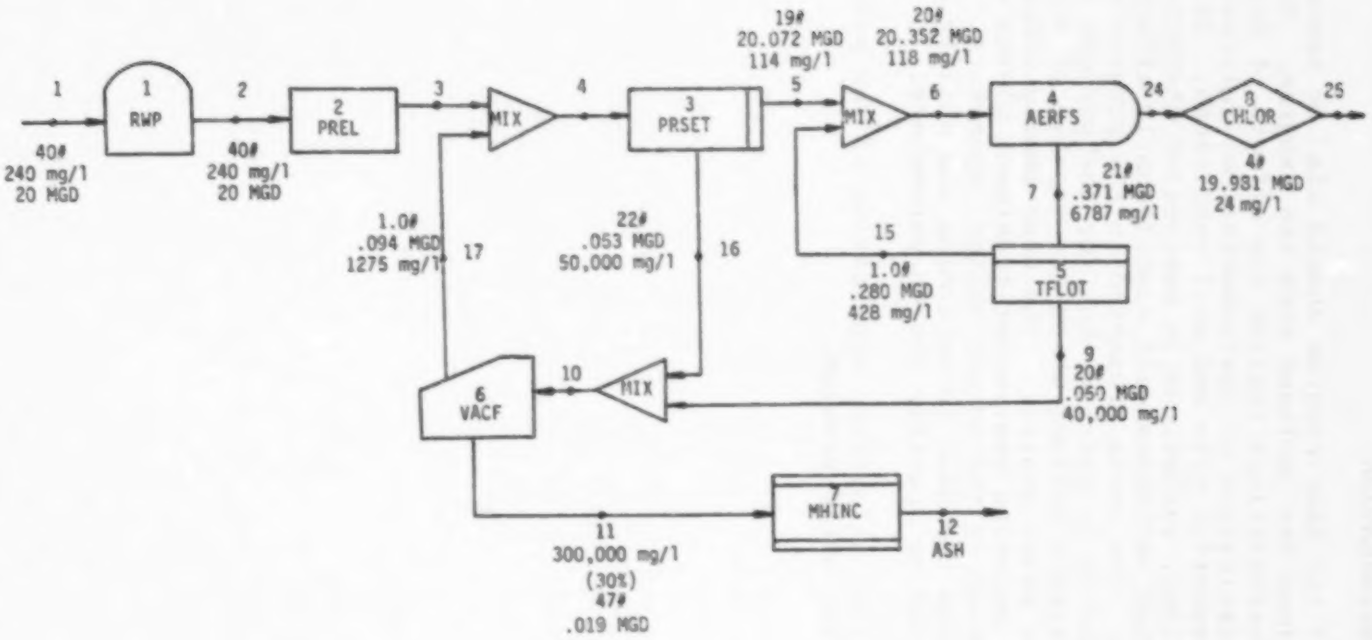
OMITTED COST CONSIDERATION

The user of the Exec Program should also be aware of various cost considerations not included with the program. These omitted cost considerations include the effects of design conservatism, sophistication of instrumentation, fail-safe design, aesthetics and specific site and soil conditions. Idiosyncrasies in local conditions, variations in wastewater characteristics and numerous other variables will significantly affect costs for specific plants. The costs presented in the program are therefore not intended to be precise, but for the purpose of comparing alternative treatment systems which are capable of achieving comparable effluent water quality. The user should compare the actual costs of existing wastewater treatment plants with Exec Program costs based on the actual design parameters. This comparison will allow the user to determine the ability of the program to respond to specific design parameters.

The Appendices illustrate application of the previous material to a real world problem.

APPENDIX A

Example Problem Configuration


1
1
RWP
40#
240 mg/1
20 MGD
2
2
PREL
40#
240 mg/1
20 MGD
3
MIX
4
3
PRSET
19#
20.072 MGD
114 mg/1
5
MIX
20#
20.352 MGD
118 mg/1
6
4
AERFS
24
8
CHLOR
25
4#
19.981 MGD
24 mg/1
7
21#
.371 MGD
6787 mg/1
5
TFLOT
15
1.0#
.280 MGD
428 mg/1
9
20#
.050 MGD
40,000 mg/1
1.0#
.094 MGD
1275 mg/1
17
22#
.053 MGD
50,000 mg/1
16
MIX
10
6
VACF
11
300,000 mg/1
(30%)
47#
.019 MGD
7
MHINC
12
ASH

Notes: 1) # values are 1000#/day
dry solids

GENESEE CO. SOLIDS BALANCE
AVERAGE DESIGN VALUES
FROM CONSOER TOWNSEND AND ASSOCIATES
PRELIMINARY DESIGN DATA
DECEMBER, 1970

APPENDIX B

Example Problem Output Plant Configuration

```
                              EXECUTIVE
                       DIGITAL COMPUTER PROGRAM
                                 FOR
            PRELIMINARY DESIGN OF WASTEWATER TREATMENT SYSTEMS

                                  BY
                             ROBERT SMITH
                           RICHARD G. EILERS

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                MUNICIPAL ENVIRONMENTAL RESEARCH CENTER
                    WASTEWATER RESEARCH DIVISION
                 TECHNOLOGY DEVELOPMENT SUPPORT BRANCH
                 SYSTEMS AND ECONOMIC ANALYSIS SECTION
                      CINCINNATI, OHIO    45268

                           (513) 684-7618




DESIGN CASE NO. 1

 20 MGD GENESEE COUNTY WASTEWATER TREATMENT PLANT  COST VERIFICATION

                          SYSTEM DIAGRAM
                            INPUT DATA

      K      N      PROCESS          IS1      IS2      OS1      OS2

      0      1     15  RWP             1        0        2        0
      0      2      1  PREL            2        0        3        0
      1      0      4  MIX             3       17        4        0
      0      3      2  PRSET           4        0        5       16
      0      0      4  MIX             5       15        6        0
      0      4      3  AERFS           6        0       24        7
      0      5     13  TFLOT           7        0        9       15
      0      0      4  MIX             9       16       10        0
      1      6      7  VACF           10        0       11       17
      0      7     14  MHINC          11        0       12        0
      0      8     12  CHLOR          24        0       25        0
      9      0      0                  0        0        0        0
```

APPENDIX C

Example Problem Output
Energy Consumption

```
                                    ENERGY CONSUMPTION AND COST

   20.00     20.00     20.00     20.00     20.00     20.00     20.00     20.00     20.00     20.00     20.00     20.00
   20.00     20.00     20.00     20.00     20.00     20.00     20.00     20.00     20.00     20.00     20.00     20.00
   20.00

   15.00      1.00      2.00      3.00     13.00      7.00     14.00     12.00       .00       .00       .00       .00
     .00       .00       .00       .00       .00       .00       .00       .00       .00       .00       .00       .00
   25.00

 2566.10     97.57    166.86  11695.90   1194.30    211.45    298.22    222.43       .00       .00       .00       .00
     .00       .00       .00       .00       .00       .00       .00       .00       .00       .00       .00       .00
  403.75

16896.58
```

```
                                   STREAM CHARACTERISTICS

                                                         VOLUME FLOW, MILLIONS OF GALLONS PER DAY
                                                         CONCENTRATIONS, MILLIGRAMS PER LITER

S 1.        Q        SOC       SNBC        SON        SOP        SFM       SBOD        VSS        NH3
       20.000    150.000     50.000     20.000      4.000     50.000    150.000    168.000     15.000
          ALK        DOC       DNBC         DN         DP        DFM       DBOD        TSS        NO3
      250.000    100.000     50.000     25.000      8.000    500.000     50.000    240.000       .000

S 2.        Q        SOC       SNBC        SON        SOP        SFM       SBOD        VSS        NH3
       20.000    150.000     50.000     20.000      4.000     50.000    150.000    168.000     15.000
          ALK        DOC       DNBC         DN         DP        DFM       DBOD        TSS        NO3
      250.000    100.000     50.000     25.000      8.000    500.000     50.000    240.000       .000

S 3.        Q        SOC       SNBC        SON        SOP        SFM       SBOD        VSS        NH3
       20.000    150.000     50.000     20.000      4.000     50.000    150.000    168.000     15.000
          ALK        DOC       DNBC         DN         DP        DFM       DBOD        TSS        NO3
      250.000    100.000     50.000     25.000      8.000    500.000     50.000    240.000       .000

S 4.        Q        SOC       SNBC        SON        SOP        SFM       SBOD        VSS        NH3
       20.075    149.763     49.941     19.968      3.992     50.011    149.760    167.893     15.000
          ALK        DOC       DNBC         DN         DP        DFM       DBOD        TSS        NO3
      250.000     99.875     50.000     25.008      8.004    500.000     49.885    239.851       .000

S 5.        Q        SOC       SNBC        SON        SOP        SFM       SBOD        VSS        NH3
       20.050     74.975     25.002      9.996      1.998     25.037     74.974     84.052     15.000
          ALK        DOC       DNBC         DN         DP        DFM       DBOD        TSS        NO3
      250.000     99.875     50.000     25.008      8.004    500.000     49.885    120.076       .000

S 6.        Q        SOC       SNBC        SON        SOP        SFM       SBOD        VSS        NH3
       20.464     75.958     25.732     10.118      1.983     25.694     75.905     88.302     15.000
          ALK        DOC       DNBC         DN         DP        DFM       DBOD        TSS        NO3
      250.000     98.950     50.000     25.070      8.034    500.000     49.033    124.760       .000
```

APPENDIX D

Example Problem Output
Stream Characteristics

```
S 7.        Q         SOC        SNBC        SON         SOP         SFM         SBOD         VSS          NH3
          .483    2117.332    1046.345     274.290      21.173     985.547     2073.788     5039.250      15.000
          ALK        DOC        DNBC          DN          DP         DFM         DBOD          TSS          NO3
       250.000      54.181      50.000      28.037       9.464     500.000        7.819     6024.797        .000

S 9.        Q         SOC        SNBC        SON         SOP         SFM         SBOD         VSS          NH3
          .064   14057.450    6946.922    1821.076     140.575    6543.268    13768.354    33456.732      15.000
          ALK        DOC        DNBC          DN          DP         DFM         DBOD          TSS          NO3
       250.000      54.181      50.000      28.037       9.464     500.000        7.819    40000.000        .000

S10.        Q         SOC        SNBC        SON         SOP         SFM         SBOD         VSS          NH3
          .094   26263.248   10415.723    3462.642     528.212   16110.268    26050.840    42428.702      15.000
          ALK        DOC        DNBC          DN          DP         DFM         DBOD          TSS          NO3
       250.000      66.346      50.000      27.230       9.676     500.000       19.018    60876.071        .000

S11.        Q         SOC        SNBC        SON         SOP         SFM         SBOD         VSS          NH3
          .019  127404.755   50527.363   16797.504    2562.393   78151.975   126374.348   205824.441      15.000
          ALK        DOC        DNBC          DN          DP         DFM         DBOD          TSS          NO3
      1212.767     321.048     242.553     132.097      44.026    2425.533       92.256   295313.852        .000

S12.        Q         SOC        SNBC        SON         SOP         SFM         SBOD         VSS          NH3
          .000        .000        .000        .000        .000        .000         .000         .000        .000
          ALK        DOC        DNBC          DN          DP         DFM         DBOD          TSS          NO3
          .000        .000        .000        .000        .000        .000         .000         .000        .000

S15.        Q         SOC        SNBC        SON         SOP         SFM         SBOD         VSS          NH3
          .414     123.544      61.053      16.005       1.235      57.506      121.004      294.036      15.000
          ALK        DOC        DNBC          DN          DP         DFM         DBOD          TSS          NO3
       250.000      54.181      50.000      28.037       9.464     500.000        7.819      351.542        .000

S16.        Q         SOC        SNBC        SON         SOP         SFM         SBOD         VSS          NH3
          .025   59905.019   19976.476    7987.144    1596.624   20004.365    59903.979    67157.356      15.000
          ALK        DOC        DNBC          DN          DP         DFM         DBOD          TSS          NO3
       250.000      99.875      50.000      25.008       8.004     500.000       49.885    95940.372        .000
```

APPENDIX D (Cont.)

Example Problem Output
Stream Characteristics

```
S17.         Q        SUC       SNBC        SON        SOP        SFM       SBOD        VSS        NH3
          .075     80.289     34.219     11.376      1.735     52.928     85.586    139.394     15.000
           ALK        DUC       DNBC         ON         OP        DFM       DBOD        TSS        NO3
       250.000     60.346     50.000     27.230      9.076    500.000     19.018    200.000       .000

S24.         Q        SUC       SNBC        SON        SOP        SFM       SBOD        VSS        NH3
        19.981      5.315      2.026       .688       .053      2.474      5.205     12.649     15.000
           ALK        DUC       DNBC         ON         OP        DFM       DBOD        TSS        NO3
       250.000     54.181     50.000     28.037      9.464    500.000      7.819     15.123       .000

S25.         Q        SUC       SNBC        SON        SOP        SFM       SBOD        VSS        NH3
        19.981      5.315      2.026       .688       .053      2.474      5.205     12.649     15.000
           ALK        DUC       DNBC         ON         OP        DFM       DBOD        TSS        NO3
       250.000     54.181     50.000     28.037      9.464    500.000      7.819     15.123       .000
```

APPENDIX D (Cont.)

Example Problem Output
Stream Characteristics

```
                                   PROCESS CHARACTERISTICS

                                                        CCOST = CAPITAL COST, DOLLARS
                                                        COSTO = OPERATING + MAINTENANCE COST, CENTS/1000 GAL.
                                                        ACOST = AMORTIZATION COST, CENTS/1000 GAL.
                                                        TCOST = TOTAL TREATMENT COST, CENTS/1000 GAL.

P 1  RAW WASTEWATER      HEAD        GP                                          CCOST     COSTO     ACOST     TCOST      ECF
     PUMPING            30.00     28.01                                       1434191.      .591     1.656     2.247     1.80

P 2  PRELIMINARY       IPREL                                                     CCOST     COSTO     ACOST     TCOST      ECF
     TREATMENT            1.0                                                  392825.      .597      .453     1.050     1.80

P 3  PRIMARY             FHPS      URPS      HPWK       GPS       APS      PGPM
     SEDIMENTATION        .50     400.0      14.0    1375.2    17.517      209.

                                                                                 CCOST     COSTO     ACOST     TCOST      ECF
                                                                      SETTLER  530531.      .234      .612      .846     1.20

                                                                      SLUDGE   142790.      .239      .165      .404     1.80
                                                                      PUMPS

P 4  ACTIVATED SLUDGE-    BOD      MLSS      DEGC    CAER20        DO    AEFF20      URSS       OSS      HEAD      ALHO
     FINAL SETTLER       13.0     2000.     20.00      1.00      1.00       .05      3.00    700.00     30.00       .80

                         BOD2     DOSAT      XHSS       AFS      CAER      CEDR      VAER      VNIT     MLASS     MLBSS
                        124.9      10.8     .0075     34.25      1.00      .125     4.405      .465      343.      536.

                       MLNBSS     MLDSS     MLISS      FOOD     RTURN      CNIT     ARCFD     RSIZE     CFPGL        QR
                         701.       47.      329.      77.0      .461      .32111738170.      8152.       .57     9.432

                                                                                 CCOST     COSTO     ACOST     TCOST      ECF
                                                                      AERATOR 1272171.      .000     1.469     1.469     1.20

                                                                      BLOWER   633608.     1.516      .731     2.247     1.80

                                                                      SLUDGE   267087.      .341      .308      .650     1.80
                                                                      PUMPS

                                                                      FINAL    898394.      .365     1.037     1.403     1.20
                                                                      SETTLER
```

APPENDIX E
Process Characteristics

```
P 5  FLOTATION               THR      TSS      GTM      GSTM     HPWK     DPOLY     CPOLY
     THICKENING              .95   40000.  1150.00     48.00   100.00    10.00       .45

                            ATHM       XN    ATHM1                         CCOST     COSTO     ACOST     TCOST       ECF
                          1000.0      2.0   1690.1                       604144.      .506      .697     1.204      2.00

P 6  VACUUM                  VFL     HPWK      TSS     IVACF    FECL3      CAO     CFECL      CCAO     DPOLY     CPOLY
     FILTRATION             4.90      35.     200.       1.0    42.00   176.00     .0640     .0125       .00     .0000

                              HP      AVF     PSDU                         CCOST     COSTO     ACOST     TCOST       ECF
                            70.5   3050.4   47797.                      3546809.     2.260     4.094     6.354      1.00

P 7  MULTIPLE HEARTH          NL     NINC     HPWK      SPER       WV       HV      TYPE        FC       CMG
     INCINERATION            2.0      1.0     35.0       5.0       .0  10000.0       1.0      .140      .970

                             FHA     WFYR     PSDU     ECOST    FCOST
                           3120. 1772889.   47830.     8196.   33178.

                                                                           CCOST     COSTO     ACOST     TCOST       ECF
                                                                        2408854.     1.467     2.781     4.247      1.00

P 8  CHLORINATION-          DCL2     TCL2     CCL2      DSO2     CSO2     BVOL      CUSE      SUSE
     DECHLORINATION         8.00     30.0   220.00       .00   180.00   83475.    243.00       .00
                                                                           CCOST     COSTO     ACOST     TCOST       ECF
                                                         CONTACT         250636.      .000      .289      .289      1.50
                                                         BASIN

                                                         CL2 FEED        203777.      .990      .235     1.225      1.20
                                                         SYSTEM

                                                         SO2 FEED             0.      .000      .000      .000      1.20
                                                         SYSTEM
```

APPENDIX E (Cont.)

Example Problem Output
Process Characteristics

```
ADMINISTRATIVE
AND LABORATORY                                        CCOST      COSTO      ACOST      TCOST
                                                      397530.     .562       .459      1.021

GARAGE
AND SHOP                                              CCOST      COSTO      ACOST      TCOST
                                                      118976.     .000       .137       .137

LABORATORY         XLAB
OPERATION            1.0                              CCOST      COSTO      ACOST      TCOST
                                                          0.      .505       .000       .505

YARDWORK
OPERATION                                             CCOST      COSTO      ACOST      TCOST
                                                          0.      .368       .000       .368
```

APPENDIX E (Cont.)

Example Probelm Output
Process Characteristics

```
                              TOTAL PLANT COST

                  TOTAL CAPITAL COST =  13102243. DOLLARS               TOT
              TOTAL AMORTIZATION COST =     15.125 CENTS/1000 GALLONS    TAMM
                     TOTAL O + M COST =     10.540 CENTS/1000 GALLONS    TOPER
                 TOTAL TREATMENT COST =     25.665 CENTS/1000 GALLONS    TOTAL


  CCI       WPI        RI        YRS       DHR       PCT        DA      CCINT     XLAB      CKWH

  2.500     1.862      .068      25.0      6.00      .150     10000.     .10      1.00      .030


 RATIO      TCAP      YARD       TCC      XLAND      ENG      SUBT1      FISC     SUBT2     XINT

  1.422   9214512.  1290032.  10504544.  281124.   786476.  11572143.  53760.  11625904.  1476340.

  ACRE       AF

  28.11     .08427
```

APPENDIX F

Example Problem Output
Total Plant Cost

CASE IV WORKSHOP

MODIFICATION OF EXISTING EXEC PROGRAM SUBROUTINES

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ABSTRACT

A procedure is presented for modifying the existing subroutines in the Exec Program for Wastewater Treatment Design developed by Smith and Eilers of the USEPA. The user can now tailor the process models of the various subroutines to meet his specific design needs. The procedure is demonstrated on the original trickling filter subroutine, TRFS. The Eckenfelder model is replaced by the Galler and Gotaas model. An analogous assigned problem of modifying the second stage anaerobic digester subroutine, DIG2, is presented as an exercise for the participants.

INTRODUCTION

One of the interesting facets of engineering design is the fact that an engineer can establish criteria, size and components for a project in a variety of ways. An office or commercial building, for example, could be designed as a steel, concrete, or timber structure. Moreover, technical procedures for calculating structural sizes and quantities could originate with several codes or as specialized design formulae developed by the designer.

When the authors of the Exec Program first selected the processes which would be included in the total package, one of their principal concerns was the choice of process design equations to use for each subroutine. An examination of current treatment facility design texts will disclose that cost processes can be described by several mathematical models. In order to meet the needs of the majority of the potential users the authors selected the most widely used process model when they formulated the FORTRAN coding for the process subroutines. The users who have worked with the Exec Program in engineering practice have found that the subroutines, for the most part, satisfy their design requirement. Notwithstanding the overall utility of the Program, many users have found it necessary to modify at least one subroutine to meet a specific design need. It is anticipated that future users will also find it necessary to tailor several subroutines for specific design tasks. Therefore, it is the purpose of this paper to outline the procedure for modifying the subroutines and to show by example how the procedure was applied.

MODIFICATION PROCEDURE

All of the process subroutines can be modified by the user who has a modest knowledge of FORTRAN and who is familiar with the Subroutine User's Guides. He should be cautioned, however, that a change in a subroutine or EXECMAIN could significantly interfere with other parts of the Exec Program if he is not careful. Fortunately, most problems can be avoided by referring to a simple checklist presented in Table 1.

DMATX, Process Design Criteria

The first step in modifying one of the subroutines is to review the process design criteria of the original version and decide whether additions, deletions or substitutions are needed. The user should watch for a change in engineering units or a need to renumber the DMATX (I,N) sequence.

Table 1. Checklist for Modifying an Exec Program Subroutine

1. DMATX, Process Design Criteria
   a. Additional Criteria
   b. Fewer Criteria
   c. Removal or Replacement of Criteria

2. COMMON, Initial Common Statements
   a. Changes in the number of Arrays
   b. Changes in Array dimensions
   c. Additional COMMON/.../... Statements
   d. Additional or modified arguments or parameters

3. Algebraic Statements
   a. Changes in process sizing equations
   b. Changes in stream constituent equations
   c. Changes in cost equations

4. OMATX, Process Parameters in Output Array
   a. New parameters to be included in output
   b. Replacement or deletion of output parameters

5. PRINT Subroutine
   a. Changes in labeling format
   b. Additional pages or tables of output
   c. Format for new subroutines

6. SMATX, Stream Constituents
   a. Additional Stream Constituents
   b. An additional Input or Output Stream for the process

7. COST Subroutine
   a. Are new cost equations compatible with COST Subroutine

8. ENERGY Subroutine
   a. New or modified equations for process energy

Initial Common Statements

Parameters and arrays which have been defined in the COMMON statement may need revision. If an additional parameter or array must be added, which will be passed to the other subroutines, then it is necessary to make the changes in the COMMON statement of all other subroutines and the EXECMAIN. Sometimes a few new parameters are added which are only passed to several subroutines. In such cases a labeled COMMON statement, COMMON/name/..., can be added to the pertinent subroutines. Occasionally array sizes must be enlarged. If so, then all the subroutine COMMON statements must be adjusted to reflect the new array size.

Algebraic Statments

Nearly all modifications affect the subroutine's algebraic statements. A new mathematical process model which replaces the original one necessitates changes in the process sizing equations and possibly the stream constituent equations as well. If a process sizing equation has a cumbersome arrangement of expressions, the original subroutine may have been simplified by assigning several FORTRAN identifiers or names to several groups of expressions. These names were then employed in the process sizing equations. It is important, therefore, to eliminate the grouped expressions from the original subroutine or make them compatible with the new process sizing equations. A new process model may also affect some of the stream constituent calculations e.g. all solid constituents or all dissolved constituents or all carbon related constituents. Some constituents may be calculated within a loop and may have to be removed from the loop if it is to be calculated by a new equation. Modifying the cost equations is easier because they can be readily identified. For example, a new curve for the energy consumption for a given process can be added without requiring a change in the equation for operating cost. A change in the capital cost curve does not require a change in the amortized cost equations. It is important, however, that each cost relationship is examined to be certain that all necessary changes are made.

OMATX, Process Parameters in Output Array

When a subroutine is altered it may be necessary to include an additional calculated parameter among those printed in the output. On the other hand, it may be necessary to eliminate from the output one or more of the parameters which were originally included. The user should check the latter section of the subroutine FORTRAN statements where parameters are assigned to OMATX (I,N). As the Exec Program now stands, as many as 20 parameters may be assigned to OMATX for a give process.

PRINT, Subroutine

All changes in OMATX assignments necessitate changes in the PRINT subroutine since it specifies the format and labeling used in the printed output. Each process subroutine has its format section in the PRINT subroutine labeled for ease of checking. The user should be careful when examining long character strings in these format statements.

SMATX, Stream Constituents

Some users may want to enhance a process by adding a second input and/or output stream. This could affect several sections of the program. A recheck of the process sizing equations must be made to determine whether the new streams should be included. In addition, the user must develop equations for calculating the 19 constituents in each of the new process streams. Both of these tasks create a host of potential error situations. Finally, the user may wish to assign a new constituent to SMATX (20,I) which is not currently used. If a subroutine modification requires several new constituents then the user must expand the number of rows in SMATX and TMATX which are currently (20,30) arrays. Such a change affects SMATX and TMATX in all subroutines. Moreover, adjustments must be made in lines EXEO5600 and EXEO7500 of EXECMAIN. This is a major modification and the user should be cautious with each change he makes.

COST Subroutine

At present (August 1977), the ENERGY subroutine, which is the most recent addition to the Exec Program library, includes simple relationships between equivalent kilowatt hour requirements for each process and the raw sewage flow. The energy relationships are being enhanced as the Exec Program evolves. Users should examine and modify, if necessary, the pertinent process energy equations in the ENERGY subroutine when modifying one of the process subroutines.

ENGINEERING EXAMPLE

The existing trickling filter process model was developed by Roesler and Smith (1969) from the work of Eckenfelder (1961) and Howland (1957) for use with the Exec Program. It is one of several models used by designers in sizing trickling filters (Schroeder, 1977). Others include equations by Gallers and Gotaas, National Research Council, and Velz. Some design offices frequently size trickling filters by several equations and temper the final design with engineering judgment. Other offices have a preference for one model when employing synthetic media for an industrial application and a different model when sizing a rock media for a domestic wastewater treatment facility. This paper explains the development of a second trickling filter subroutine for the Exec Program library based upon the Galler and Gotaas (1964) trickling filter model.

Existing Model

Appendix A presents the derivation of the existing model Basically Roesler and Smith (1969) start with first order kinetics (equation 1) and an empirical travel time expression for a particle of water (equation 2) and develop an equation for required filter depth as a function of design criteria specified by the user. These include effluent BOD, hydraulic loading rate, specific surface area, temperature and recirculation factor. Figure 1 depicts the trickling filter flow diagram used in the derivation. It depicts the recylce stream being withdrawn and returned to the head of the filter without passing through the final settling tank. Such an arrangement leads to an equation for filter effluent BOD in terms of the known influent wastewater BOD and the specified settler effluent BOD. Other trickling filter flow diagrams can be described in terms of the equations of Roesler and Smith (1969). Several of these are presented in Figure 2. The principal difference would lie in the materials balance equations across the filters and final settling tanks. A key assumption in Roesler and Smith's development is that BOD in both the suspended solid form and in the dissolved form are removed at the same rate as the wastewater passes through the filter.

New Model

Derivation--

Appendix B presents the derivation of the trickling filter process equations based upon the Galler and Gotaas model (1964). Figure 1 shows the associated schematic flow diagram. Their model is an empirical formula based upon regression analysis in which effluent BOD from a trickling filter is correlated wit influent BOD, hyrdaulic loading rate, recirculation rate, temperature and depth. Unlike the Eckenfelder equation, the Galler and Gotaas equation does not include specific surface area as an independent variable.

When attempting the derivation, it becomes apparent within a short time that an explicit solution of depth in terms of known variables is not possible. The effluent BOD is related to the influent BOD by the 1.19 power and the influent BOD is not explicitly known. One way of attacking the problem is a trial and error solution. Basically, values are assumed for the total and dissolved BOD in the filter influent as well as filter effluent BOD. The depth is then approximated and used to recalculate the filter effluent BOD. The final settler effluent BOD is calculated and compared with the design specified final settler BOD. Unless the calculated and specified BOD are

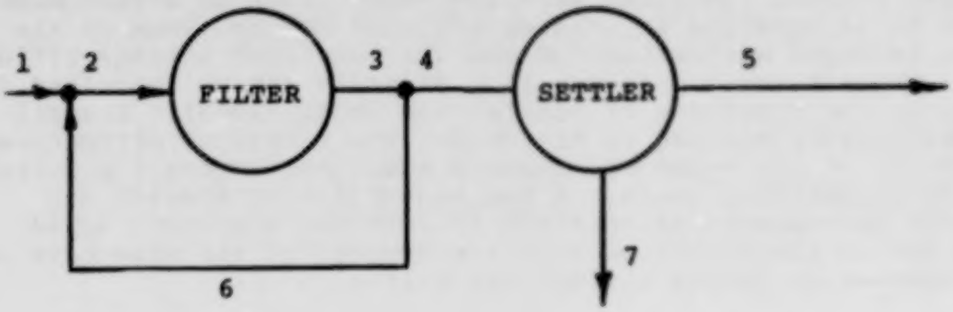
1
2
FILTER
3
4
SETTLER
5
6
7

Figure 1. Schematic Diagram of Trickling Filter

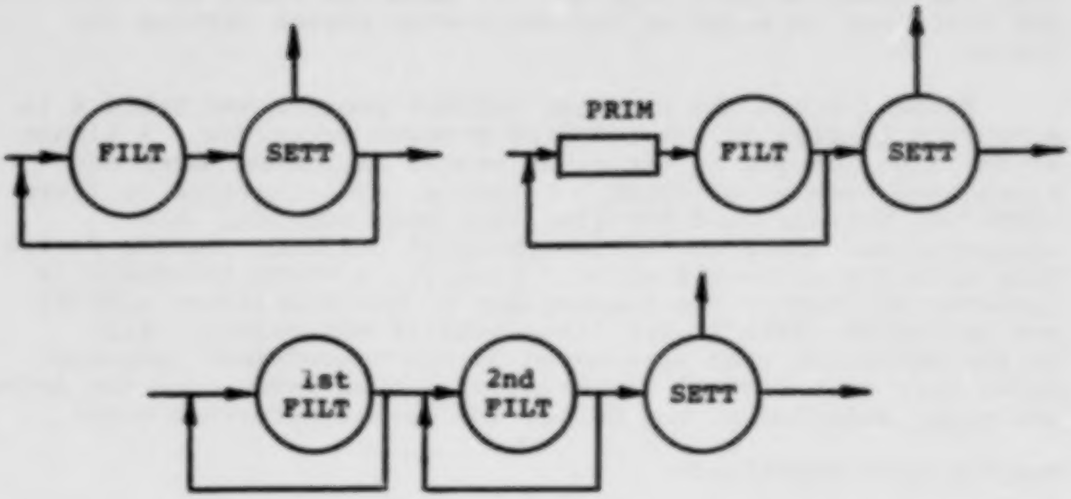
FILT
SETT
PRIM
FILT
SETT
1st FILT
2nd FILT
SETT

Figure 2. Alternative Trickling Filter Schematic Diagrams

within the allowable error, the effluent BOD is refined to a value halfway between the calculated and specified values. The refined effluent value is then used to recalculate the depth. This cycle continues until the allowable error between the two values is attained. Magnitude of allowable error determines the accuracy of the filter depth required and the number of iterative loops needed to obtain a satisfactory calculated effluent BOD. To illustrate this effect, filter depth calculations were made using errors of 0.6 and 0.4 mg/l. The results, which are presented in Table 2, indicate that the error in the depth calculation increases as the required depth becomes larger. An error of 0.1 mg/l was also tried; however, the limit on the number of iterative loops was exceeded before the error tolerance was met. A value of 0.4 mg/l was therefore selected.

As in the original subroutine derivation, it is assumed that the reaction rate constant for both the solid and dissolved BOD fractions is equal as the wastewater passes through the filter.

Table 3 lists the original FORTRAN program and Table 4 is a FORTRAN listing of the modified process equations. A glance at the line numbers in the right margin indicates which equations have been substituted. Moreover, the equations on lines TRFO2200, TRF03300 and TRF03500 have been removed. The statement two lines above line TRF03100 compares the BOD derivation with the allowable error. Finally, a WRITE statement is included to observe the convergence of the calculated (CHECK) and specified (DMATX(1,N)) final settler BOD values. All of the equations that were based on the Eckenfelder reference model have been removed or replaced by ones based upon the trial and error solution of the Galler and Gotaas reference model.

Modification Checklist--

Table 1 serves as a useful checklist for reviewing the modifications made on the original trickling filter subroutine. The numbered comments below refer to the numbered points on the checklist.

1. DMATX (4,N) SAREA was not deleted even though it is not used as a design criteria for the Galler and Gotaas model. Had it been removed, the other DMATX criteria would have needed renumbering. Renumbering would have affected many of the process equations as well as the PRINT subroutine which formats the labels for printing all DMATX values.

2. The COMMON statements were not altered.

Table 2.

Effect of Acceptable Error Magnitude on Predicted Depth

Case 1. DMATX(1,N) BOD Varied from 12 to 30 mg/l

Filter Depths (ft.)

	Acceptable Error (mg/l)	
BOD	0.6	0.4
12 mg/l	25.4 ft.	25.0 ft.
15	18.4	18.0
18	14.0	13.8
21	11.2	11.1
24	9.2	9.2
27	7.8	7.8
30	6.7	6.7

Case 2. DMATX(3,N) HQ Varied from 5 to 30 mgd/acre

	Acceptable Error (mg/l)	
HQ	0.6	0.4
5	9.7	9.6
10	11.2	11.1
15	12.2	12.1
20	12.9	12.9
25	13.6	13.5
30	13.6	14.0

TABLE 3

Fortran Listing of Original Process Equations

```
C                                                                       TRF00100
C                 TRICKLING FILTER - FINAL SETTLER                      TRF00200
C                 PROCESS IDENTIFICATION NUMBER  11                     TRF00300
C                                                                       TRF00400
      SUBROUTINE TRFS                                                   TRF00500
C                                                                       TRF00600
C                                                                       TRF00700
C                 COMMON INITIAL STATEMENTS                             TRF00800
C                                                                       TRF00900
      INTEGER OS1,OS2                                                   TRF01000
      COMMON SMATX(20,30),TMATX(20,30),DMATX(20,20),OMATX(20,20),IP(20),TRF01100
     1INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(20,5),COSTO(20,5),ACOST(20,5)TRF01200
     2,TCOST(20,5),DHR,PCT,WPI,CLAND,DLAND,FLOW(25),POW(25),TKWHD(25)   TRF01300
C                                                                       TRF01400
C                                                                       TRF01500
C                 PROCESS RELATIONSHIPS REQD. TO CALC. EFFLUENT STREAM  TRF01600
C                 CHARACTERISTICS                                       TRF01700
C                                                                       TRF01800
      HEAD=DMATX(9,N)                                                   TRF01900
      BODIN=SMATX(8,IS1)+SMATX(17,IS1)                                  TRF02000
      BETA=.0245*1.035**(DMATX(2,N)-20.)                                TRF02100
      XN=.91-6.45/DMATX(4,N)                                            TRF02200
      QB=DMATX(7,N)*SMATX(2,IS1)                                        TRF02300
      RHQ=((DMATX(7,N)+1.)*DMATX(3,N))**XN                              TRF02400
      BOD=(SMATX(17,IS1)+DMATX(6,N)*SMATX(8,IS1))/DMATX(1,N)            TRF02500
      DEPTH=RHQ*ALOG((BOD+DMATX(7,N))/(DMATX(7,N)+1.))/(BETA*DMATX(4,N))TRF02600
      XPO=EXP(BETA*DMATX(4,N)*DEPTH/RHQ)                                TRF02700
      BODO=BODIN/(XPO*(DMATX(7,N)*(1.-1./XPO)+1.))                      TRF02800
      DBODO=SMATX(17,IS1)/(XPO*(DMATX(7,N)*(1.-1./XPO)+1.))             TRF02900
      SBOD4=BODO-DBODO                                                  TRF03000
      SBOD5=SBOD4*DMATX(6,N)                                            TRF03100
      BETAN=.00307*1.141**(DMATX(2,N)-20.)                              TRF03200
      XPON=EXP(BETAN*DMATX(4,N)*DEPTH/RHQ)                              TRF03300
      SON4=SMATX(5,IS1)*SBOD4/SMATX(8,IS1)                              TRF03400
      DN4=(SMATX(13,IS1)+SMATX(5,IS1)-SON4)/(XPON+(XPON-1.)*DMATX(7,N)) TRF03500
      DN5=DN4                                                           TRF03600
      SON5=SON4*DMATX(6,N)                                              TRF03700
C                                                                       TRF03800
C                                                                       TRF03900
C                 EFFLUENT STREAM CALCULATIONS                          TRF04000
C                                                                       TRF04100
      SMATX(2,OS1)=SMATX(2,IS1)*(1.-DMATX(5,N))/(DMATX(6,N)-DMATX(5,N)) TRF04200
      SMATX(2,OS2)=SMATX(2,IS1)*(1.-DMATX(6,N))/(DMATX(5,N)-DMATX(6,N)) TRF04300
      SMATX(4,OS1)=SMATX(4,IS1)*DMATX(6,N)                              TRF04400
      SMATX(4,OS2)=SMATX(4,IS1)*DMATX(5,N)                              TRF04500
      SMATX(5,OS1)=SON5                                                 TRF04600
      SMATX(5,OS2)=SON4*DMATX(5,N)                                      TRF04700
      SMATX(6,OS1)=SMATX(6,IS1)*DMATX(6,N)*SBOD4/SMATX(8,IS1)           TRF04800
      SMATX(6,OS2)=SMATX(6,IS1)*DMATX(5,N)*SBOD4/SMATX(8,IS1)           TRF04900
      SMATX(7,OS1)=SMATX(7,IS1)*DMATX(6,N)                              TRF05000
      SMATX(7,OS2)=SMATX(7,IS1)*DMATX(5,N)                              TRF05100
      SMATX(8,OS1)=SBOD4*DMATX(6,N)                                     TRF05200
      SMATX(8,OS2)=SBOD4*DMATX(5,N)                                     TRF05300
      SMATX(9,OS1)=SBOD4*DMATX(6,N)+SON5+SMATX(4,IS1)*DMATX(6,N)        TRF05400
      SMATX(9,OS2)=SBOD4*DMATX(5,N)+SON4*DMATX(5,N)+SMATX(4,IS1)*DMATX(5TRF05500
     1,N)                                                               TRF05600
      SMATX(10,OS1)=SMATX(9,OS1)+SMATX(7,OS1)+SMATX(6,OS1)              TRF05700
      SMATX(10,OS2)=SMATX(9,OS2)+SMATX(7,OS2)+SMATX(6,OS2)              TRF05800
```

TABLE 4

Fortran Listing of Modified Process Equations

```
C                                                                       TRF00100
C          TRICKLING FILTER - FINAL SETTLER                             TRF00200
C          PROCESS IDENTIFICATION NUMBER  11                            TRF00300
C                                                                       TRF00400
      SUBROUTINE TRFS                                                   TRF00500
C                                                                       TRF00600
C                                                                       TRF00700
C          COMMON INITIAL STATEMENTS                                    TRF00800
C                                                                       TRF00900
      INTEGER OS1,OS2                                                   TRF01000
      COMMON SMATX(20,30),TMATX(20,30),DMATX(20,20),OMATX(20,20),IP(20),TRF01100
     1INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(20,5),COSTO(20,5),ACOST(20,5)TRF01200
     2,TCOST(20,5),DHR,PCI,WPI,CLAND,DLAND,FLOW(25),POW(25),TKWHD(25)   TRF01300
C                                                                       TRF01400
C                                                                       TRF01500
C          PROCESS RELATIONSHIPS REQD. TO CALC. EFFLUENT STREAM         TRF01600
C          CHARACTERISTICS                                              TRF01700
C                                                                       TRF01800
      HEAD=DMATX(9,N)                                                   TRF01900
      BODIN=SMATX(8,IS1)+SMATX(17,IS1)                                  TRF02000
      BETA=.0245*1.035**(DMATX(2,N)-20.)                                TRF02100
      GG=DMATX(7,N)*SMATX(2,IS1)                                        TRF02300
      LOOP=0
      BOD2=BODIN
      DBOD2=SMATX(17,IS1)
      BOD4=DMATX(1,N)
      GNG1=(0.404*(1.+DMATX(7,N))**0.28*DMATX(3,N)**0.15)/(DMATX(2,N)**
     .0.15)
    2 DEPTH=(BOD2**1.19*GNG1/BOD4)**1.5-1.
      LOOP=LOOP+1
      IF(LOOP.GT.25) GO TO 6
      GNG=GNG1/(1.+DEPTH)**0.67
      BOD4=BOD2**1.19*GNG
      DBOD4=BOD4*(DBOD2/BOD2)**1.19
      CHECK=BOD4*DMATX(6,N)+DBOD4*(1.-DMATX(6,N))
      WRITE(10,4) CHECK,BOD2,DBOD2,BOD4,DBOD4,DEPTH
    4 FORMAT('0',6F10.4)
      BOD4T=BOD4
      BOD4=BOD4+0.5*(DMATX(1,N)-CHECK)
      DBOD4=BOD4/BOD4T*DBOD4
      BOD2=(BODIN+BOD4*DMATX(7,N))/(1.+DMATX(7,N))
      DBOD2=SMATX(17,IS1)+DBOD4*DMATX(7,N)/(1.+DMATX(7,N))
      IF(ABS(CHECK-DMATX(1,N)).GE.0.4) GO TO 2
    6 SBOD4=BOD4-DBOD4
      SBOD5=SBOD4*DMATX(6,N)                                            TRF03100
      BETAN=.00507*1.141**(DMATX(2,N)-20.)                              TRF03200
      SON4=SMATX(5,IS1)*SBOD4/SMATX(8,IS1)                              TRF03400
      DN4=BETAN/BETA*(SMATX(15,IS1)+SMATX(5,IS1)-SON4)
      DN5=DN4                                                           TRF03600
      SON5=SON4*DMATX(6,N)                                              TRF03700
C                                                                       TRF03800
C                                                                       TRF03900
C          EFFLUENT STREAM CALCULATIONS                                 TRF04000
C                                                                       TRF04100
      SMATX(2,OS1)=SMATX(2,IS1)*(1.-DMATX(5,N))/(DMATX(6,N)-DMATX(5,N)) TRF04200
```

3. Extensive changes were made in the algebraic process sizing equations. No changes were needed in the stream or cost equations.

4. The OMATX definitions and values were not altered.

5. Since the DMATX numbering was not changed, the PRINT subroutine remained satisfactory.

6. SMATX values were unaffected.

7. COST was unaffected.

8. No changes were needed in the ENERGY subroutine.

COMPARATIVE RESULTS

Once the modified subroutine was checked and debugged, it was compared with the original subroutine. To simplify the comparison, a one process system consisting solely of a trickling filter final settler was evaluated. It was programmed to treat the typical raw sewage stream which is quantified in the EXECMAIN User's Guide. Both trickling filter subroutines were evaluated to characterize their relationships between (1) hydraulic loading rate and filter depth, (2) effluent BOD requirement and filter depth, and (3) recirculation factor and filter depth. Table 5 summarizes the input conditions for the single process calculations.

The results of the Exec Program calculations are presented in Figures 3a, 3b, and 3c. The Galler and Gotaas model (1964) predicts a broader range of filter depths as a function of final settler BOD than does the Eckenfelder model (1961). On the other hand, a broader range of depths as a function of hydraulic loading rate and recirculation factor result from the Eckenfelder model than from the Galler and Gotaas model. The practical implication is that the Galler and Gotaas model is more sensitive to effluent BOD criteria and the Eckenfelder model has a greater sensitivity than the Galler and Gotaas model in terms of hydraulic loading rate and recirculation factor.

In a second comparison of the two subroutines a trickling filter process was part of a complete wastewater treatment system as depicted schematically in Figure 4. Table 6 lists the input conditions used in the Exec Program calculations on the system in Figure 4. The results are plotted for both filter models in Figure 5. The figure graphically characterizes the effect of influent BOD on the required filter depth. The data indicate that the Galler and Gotaas model is the more sensitive of the two versions to influent BOD concentrations.

Table 5.

Input Conditions - Single Process Calculations

SMATX(I,1) I = 2,20	Same as typical raw sewage composition listed in EXECMAIN Users Guide
DMATX(I,20) I = 1,10	Same as typical cost parameters listed in EXECMAIN Users Guide
DMATX(1,N) BOD	Varied with each run (12-30) mg/l
DMATX(2,N) DEGC	20.0°C
DMATX(3,N) HQ	Varied 5-30 mgd/acre
DMATX(4,N) SAREA	10 ft^2/ft^3
DMATX(5,N) URSS	Varied 2-100
DMATX(6,N) XRSS	0.6
DMATX(7,N) RECYCL	Varied 0.5-5
DMATX(8,N) GSS	2000 gpd/ft^2
DMATX(9,N) HEAD	30.0 ft
DMATX(14,N) ECF	1.0
DMATX(15,N)	1.0
DMATX(16,N)	1.0

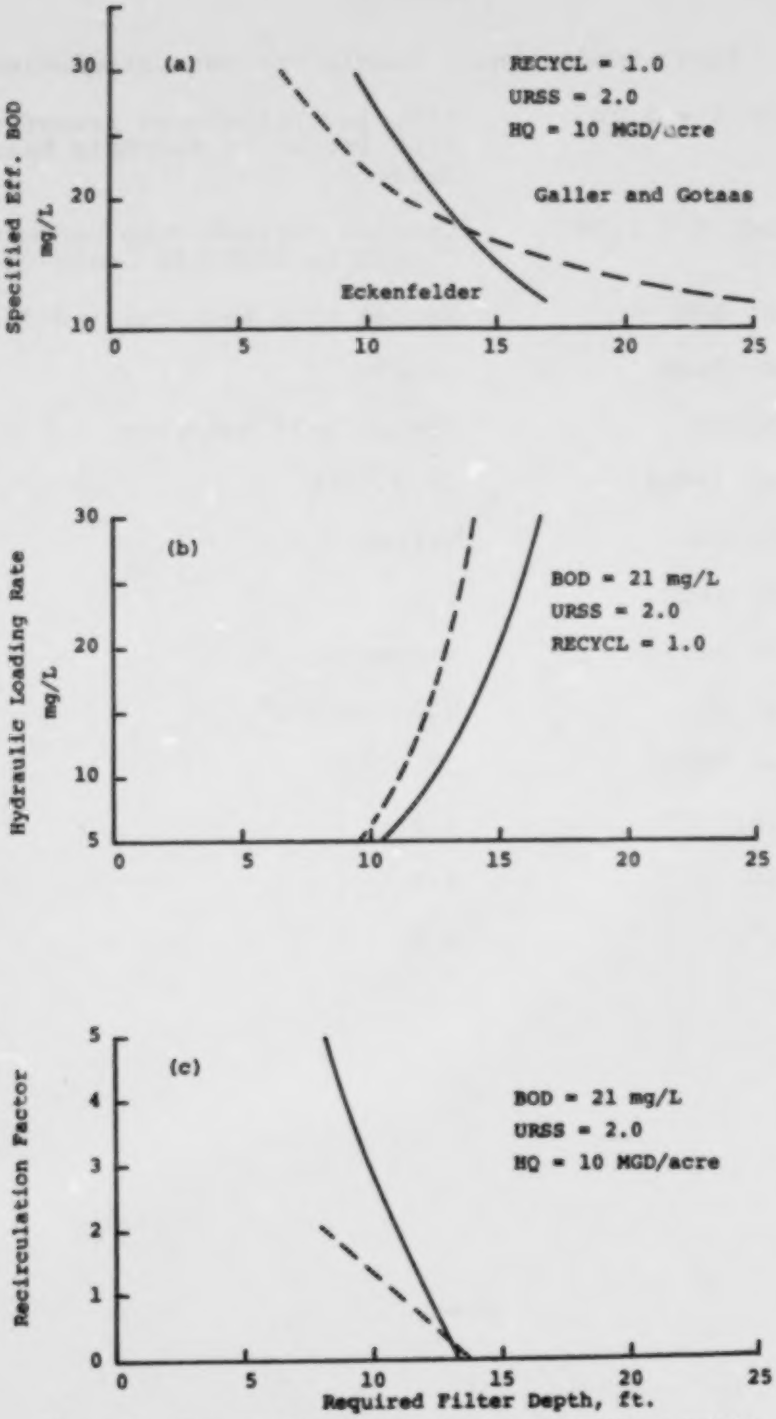

Figure 3. Process Characteristics of Both Filter Models

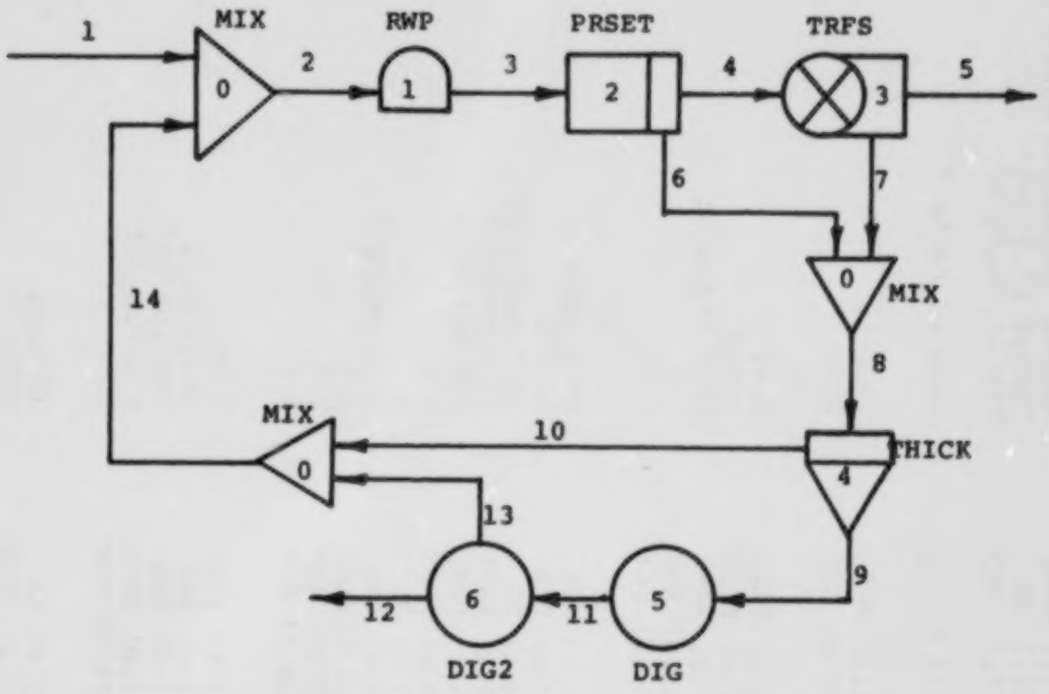
1
MIX
0
2
RWP
1
3
PRSET
2
4
TRFS
3
5
6
7
0
MIX
14
8
MIX
10
THICK
0
4
13
9
6
5
12
11
DIG2
DIG

Figure 4. Example System Flow Diagram

Table 6.

Input Conditions - Treatment Facility System Calculations

SMATX(I,1) I = 2,20	Same as Table 7 except:
SMATX(3,1) SOC	Varied 53,105,158 mg/l
SMATX(8,1) SBOD	Varied 70,140,210 mg/l
SMATX(11,1) DOC	Varied 22,43,65
SMATX(17,L) DBOD	Varied 30,60,90
DMATX(I,20) I = 1,10	Same as Table 7
RWP	
DMATX(1,N) EHAD	30.0 ft.
DMATX(16,N) ECF	1.0
PRSET	
DMATX(1,N) FRPS	0.50
DMATX(2,N) RIPS	200.0
DMATX(3,N) HPWK	14.0 hrs/week
DMATX(15,N) ECF	1.0
DMATX(16,N) ECF	1.0
TRFS	
DMATX(1,N) BOD	20.0 mg/l
DMATX(2,N) DEGC	20.0°C
DMATX(3,N) HQ	10.0 mgd/acre
DMATX(4,N) SAREA	10.0 ft^2/ft^3
DMATX(5,N) URSS	2.0 and 50.0
DMATX(6,N) XRSS	0.6
DMATX(7,N) RECYCL	1.0
DMATX(8,N) GSS	2000 gpd/ft^2
DMATX(14,N) ECF	1.0
DMATX(15,N) ECF	1.0
DMATX(16,N) ECF	1.0
THICK	
DMATX(1,N) TRR	0.95
DMATX(2,N) TSS	50000 mg/l
DMATX(3,N) GTH	700 gpd/ft^2
DMATX(4,N) GSTH	8 $lb/day/ft^2$
DMATX(16,N) ECF	1.0
DIG	
DMATX(1,N) TD	15 days
DMATX(2,N) TDIG	35°C
DMATX(16,N) ECF	1.0
DIG2	
DMATX(1,N) TRR	0.81
DMATX(2,N) TSS	50000 mg/l
DMATX(3,N) TD	1.5 days
DMATX(16,N) ECF	1.0

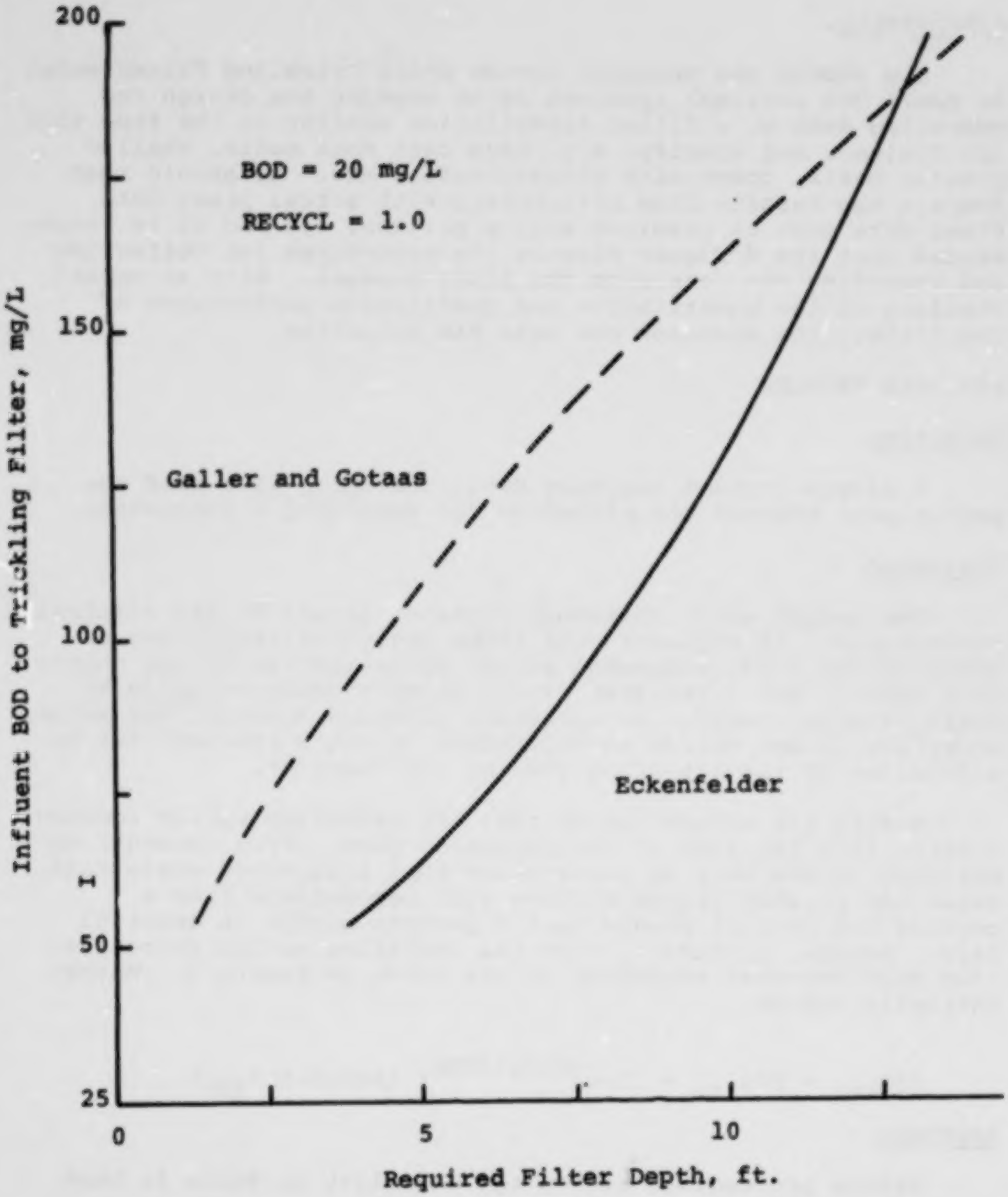

Figure 5. Effect of Influent BOD on Required Trickling Filter Depth

Application.

How should the designer decide which trickling filter model to use? One rational approach is to examine the design and operating data of a filter installation similar to the type that the designer may specify, e.g. high rate rock media, shallow plastic media, tower with plastic media, etc. He should then compare the results from both models with actual plant data. Plant data must be examined with a critical eye and it is recommended that the designer discuss the procedures for collecting and recording the data with the plant manager. With an understanding of the quantitative and qualitative performance of the filter, the designer can make his selection.

ASSIGNED PROBLEM

Objective

A simple problem has been developed which will lead the participant through the procedure for modifying a subroutine.

Statement

The second stage anaerobic digester is one of the simplest subroutines. It requires only three design criteria, one of which is the total suspended solids concentration in the underflow stream, OS1. The user simply picks a constant which he feels is appropriate. In operating practice however. the actual underflow sludge solids concentration is not a constant but is a function of the detention time of the digester.

Modify the subroutine so that the underflow solids concentration is a function of the detention time. From personal experience it has been my observation that a digested waste activated and primary sludge mixture will concentrate from a nominal 2-4 percent sludge to a 6 percent sludge in about 45 days. Assume, therefore, that the underflow solids concentration will increase according to the curve in Figure 6. Mathematically stated

$$TSS_{OS1} = TSS_{IS1} + (1-e^{-0.111(TD)})\ (60000-TSS_{IS1})$$

Approach

Before proceeding, review the checklist in Table 1; then proceed as follows:

1. Refer to the User's Guide and note all FORTRAN statements that depend upon DMATX (2,N), TSS_{OS1}, especially those stream constituents which are of a solid nature.

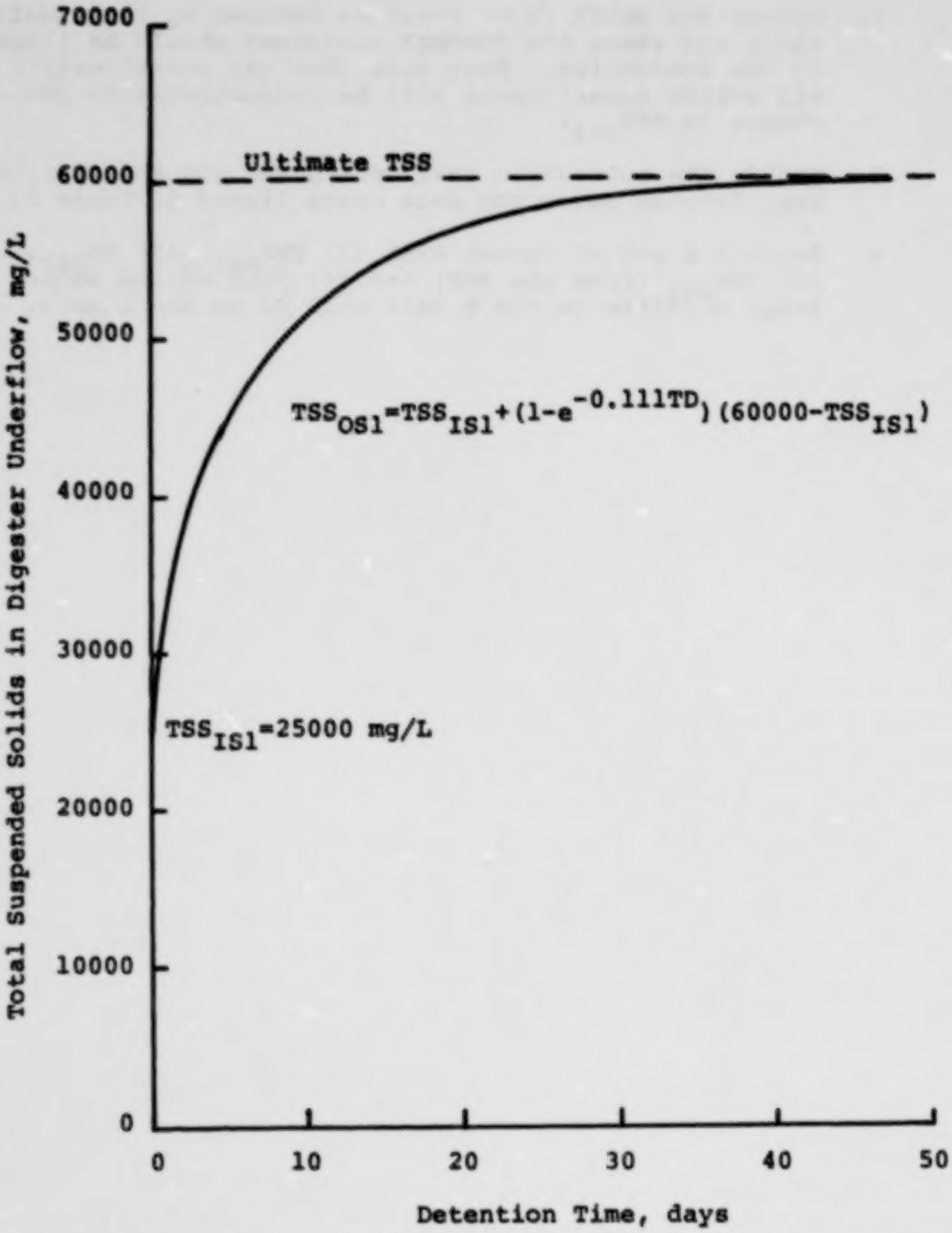

Figure 6. Total Suspended Solids in Digester Underflow as a Function of Detention Time

2. Decide how DMATX (2,N) could be defined by the equation above and where the FORTRAN statement should be placed in the subroutine. Make sure that the concentration of all solids constituents will be proportional to the change in TSS_{OS2}.

3. Modify the subroutine card deck given you and run the Exec Program using the data cases listed in Table 7.

4. Prepare a set of curves with (1) TSS_{OS1}, (2) DN_{OS1}, (3) TSS_{OS1} (from the RWP) and (4) COST of the second stage digester on the Y axis with TD on the X axis.

Table 7.

Listing of Data Cards for Assigned Problem

```
12345678911234567892123456789312345678941234567895123456789612345678971234567898

 0 1 1
ASSIGNED SUBROUTINE MODIFICATION
       10.      105.       30.       10.        2.       30.      140.      224.
      254.       43.       11.       1 .        4.      500.      250.       60.
       15.        0.
     2.257     1.675       .06       25.      4.73       .15     1000.       .06
        0.       .02        1.
0  0   4 MIX       1        14         2         0
0  1  15 RAP       2         0         3         0
       30.
                                                                              .1
0  2   2 PRSET     3         0         4         6
        .5      260.       14.
                                                                    1.        1.
0  3  11 TRFS      4         0         5         7
       20.       20.       10.       10.       50.        .6        1.     2000.
       30.                                                1.        1.        1.
0  0   4 MIX       6         7         8         0
0  4   8 THICK     8         0         9        10
       .95    50000.      700.        8.
                                                                              1.
0  5   6 DIG       9         0        11         0
       15.       35.
                                                                              1.
0  6  21 DIG2     11         0        12        13
       .81    50000.       15.
                                                                              1.
0  0   4 MIX      10        13        14         0
9
 0 0 1
ASSIGNED SUBROUTINE MODIFICATION
 1 6
       .81    50000.       20.
                                                                              1.
 0 0 1
ASSIGNED SUBROUTINE MODIFICATION
 1 6
       .81    50000.       25.
                                                                              1.
 0 0 1
ASSIGNED SUBROUTINE MODIFICATION
 1 6
       .81    50000.       30.
                                                                              1.
 1 0 0
ASSIGNED SUBROUTINE MODIFICATION
       10.      150.       30.       10.        2.       30.      210.      224.
      254.       65.       11.       1 .        4.      500.      250.       90.
       15.        0.
 0 1 0
ASSIGNED SUBROUTINE MODIFICATION
     2.257     1.675       .06       25.      4.73       .15    20000.       .06
        0.       .02        1.

12345678911234567892123456789312345678941234567895123456789612345678971234567898
```

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Eckenfelder, W. W., Jr. 1961. "Trickling Filter Design and Performance," *Journal Sanitary Engineering Division of A.S.C.E.*, *87*, 2860.

Galler, W. S. and H. B. Gotaas. 1964. "Analysis of Biological Filter Variables," *Journal Sanitary Engineering Division of A.S.C.E.*, *90*(SA6):59-79.

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Appendix A

Derivation of Existing Trickling Filter Process Equations (1)

Assume BOD removal follows first order relationship with time.

$$dC = -k\ C\ dt \qquad (1)$$

C = BOD, mg/L
k = rate constant, 1/time

Time required for a particle to pass through depth, D, ft. was estimated by Howland as

$$t = \frac{k_a (SAREA) D}{HQ_f^{\ N}} \qquad (2)$$

k_a = constant
SAREA = specific surface area of media ft^2/ft^3
HQ_f = hydraulic loading rate through the filter, mgd/ft^2
HQ_f = $(1+R)HQ$
R = recirculation factor
HQ = hydraulic loading rate excluding recycle
N = temperature dependent rate constant

By assuming k_a and B do not vary within the filter, equation (1) can be substituted into equation (2) and integrated to

$$C = C_i e^{\left[\frac{-K(SAREA)D}{HQ_f^{\ N}}\right]} \qquad (3)$$

C_i = BOD applied to filter, mg/L
K = $(k)(k_a)$

Referring to Figure 1

$$Q_2C_2 = Q_1C_1 + Q_6C_6 \qquad (4)$$

Q = flow rate
subscripts refer to stream numbers in Figure 1

$$Q_1(1+R)C_2 = Q_1C_1 + Q_1RC_6 \tag{5}$$

$$R = Q_1/Q_6.$$

$$C_6 = C_3 \tag{6}$$

$$C_2 = \frac{C_1 + RC_3}{(1+R)} \tag{7}$$

Let $$E = e^{\frac{K(SAREA)D}{HQf^N}} \tag{8}$$

Substituting equation (9) into (3)

$$C_3 = C_2(1/E) \tag{9}$$

$$C_2 = C_3E \tag{10}$$

$$C_3E = \frac{C_1 + RC_3}{(1+R)} \tag{11}$$

$$C_3 = \frac{C_1}{E(1+R) - R} \tag{12}$$

A fundamental assumption made to complete the derivation is that dissolved BOD and solid BOD are removed at the same rate.

$$C_3 = C_{3D} + C_{3S} \tag{13}$$

$$C_{3D} = \frac{C_{1D}}{E(1+R) - R} \tag{14}$$

$$C_{3S} = \frac{C_{1S}}{E(1+R) - R} \tag{15}$$

subscripts
D = dissolved BOD
S = solid BOD

From Figure 1

$$C_4 = C_3 \qquad (16)$$

$$C_5 = C_{3D} + \text{XRSS } C_{3S} \qquad (17)$$

XRSS = fraction of influent solids removed in final settler

$$C_5 = \frac{C_{1D}}{E(1+R) - R} + \text{XRSS } \frac{C_{1S}}{E(1+R) - R} \qquad (18)$$

$$C_5 = \frac{C_{1D} + C_{1S} \text{ XRSS}}{E(1+R) - R} \qquad (19)$$

Let

$$X = \frac{C_{1D} + C_{1S} \text{ XRSS}}{C_5} \qquad (20)$$

$$E = \frac{X + R}{1 + R} \qquad (21)$$

$$e^{\left[\frac{K(\text{SAREA})D}{HQ_f^N}\right]} = \frac{X + R}{1 + R} \qquad (22)$$

Solving for D

$$D = \frac{HQ_f^N}{K(\text{SAREA})} \ln \frac{X + R}{1 + R} \qquad (23)$$

Reconciling the derivation with the TRFS FORTRAN Statements in Table 3

Replace K with BETA
where BETA is calculated by line TRF02100

Replace N with XN
where XN is calculated by line TRF02200

Replace HQf^N with RHQ
where RHQ is calculated by line TRF02400

Replace X with BOD
Equation 20 becomes line TRF02500

Replace D with DEPTH
Equation 23 becomes line TRF02600

Replace E with XPO
Equation 8 becomes line TRF02700

Replace C_3 with BODO and C_1 with BODIN
Equation 12 becomes line TRF02800

Replace C_{3D} with DBODO
Equation 14 becomes line TRF02900

Finally, replace C_{4S} with SBOD4 and C_{5S} with SBOD5

Statements TRF03200 through TRF03700 define nitrification which occurs in the filter. Note that the kinetic equations are analogous to these for BOD removal with the exception that the rate constant BETAN is significantly lower than BETA.

Appendix B

Derivation of Modified Trickling Filter Process Equations

The Galler and Gotaas (2) equation for BOD removal in a trickling filter was selected as the basic model around which the original TRFS subroutine was modified. Referring to Figure 1

$$C_3 = \frac{C_2^{1.19}(0.464)(1+R)^{0.28}(HQ_f)^{0.13}}{(1+D)^{0.67}T^{0.15}} \qquad (1)$$

where the symbols retain the definitions of Table 2

Solving for depth D

$$D = \left[\frac{C_2^{1.19}(0.464)(1+R)^{0.28}(HQ_f)^{0.13}}{C_3T^{0.15}}\right]^{3/2} -1 \qquad (2)$$

Since the empirically developed G and G equation contains fractional exponents, it was not possible to make the substitutions utilized in Table 2 for defining the unknown C_3 in terms of the known C_1 and C_5. Therefore, a trial and error procedure was used.

1. Assume value for C_2 and C_{2D}
2. Calculate $GNG1 = \frac{0.464(1+R)^{0.28}(HQ_f)^{0.13}}{T^{0.15}}$ (3)
3. Calculate depth

$$D = \left[\frac{C_2^{1.19}GNG1}{C_3}\right]^{1.5} -1 \qquad (4)$$

4. Calculate GNG

$$GNG = \frac{GNG1}{(1+D)^{0.67}} \qquad (5)$$

5. Calculate C_3 and C_{3D}

$$C_3 = C_2^{1.19} GNG \tag{6}$$

$$C_{3D} = C_3 \left[\frac{DBOD2}{BOD2}\right]^{1.19} \tag{7}$$

6. Check whether or not the calculated C_5 is within the allowable error tolerance of the C_5 value specified in the process design criteria DMATX (1,N).

Note that

$$C_4 = C_3 \tag{8}$$

$$C_3 = C_{3D} + C_{3S} \tag{9}$$

$$C_5 = C_{3D} + XRSS\ C_{3S} \tag{10}$$

$$C_5 = C_{3D} + (C_3 - C_{3D}) XRSS \tag{11}$$

If equation (11) is less than 0.4 mg/L apart from DMATX (1,N), the calculated depth is satisfactory. If not then let

$$C_3^{\,1} = C_3 \tag{12}$$

$$C_3 = C_3 + 0.5\ (DMATX(1,N) - C_5) \tag{13}$$

$$C_{3D} = \frac{C_3}{C_3^{\,1}}\ C_{3D} \tag{14}$$

7. Calculate C_2 and C_{2D} and return to Step 3

8. If the calculated C_5 is satisfactory continue through the trickling filter subroutine.

Table 4 lists the FORTRAN process equations for the modified subroutine. Note that

BOD2 replaces C_2
BOD4 replaces C_3
DEPTH replaces D
DBOD4 replaces C_{3D}
DBOD2 replaces C_{2D}
SBOD4 replaces C_{3S}
SBOD5 replaces C_{5S}

Since the G and G model does not include an equation for nitrogen removal analogous to equation (6), the degree of nitrification and denitrification was assumed proportional to the ratio BETAN/BETA. Both BETAN and BETA equations are retained from the original TRFS version.

CASE V WORKSHOP

MODIFICATION OF EXISTING EXEC PROGRAM COST RELATIONSHIPS

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ABSTRACT

The Exec Program is modified to incorporate concepts of the cost-effectiveness guidelines of the USEPA in evaluating the overall monetary worth of a system. The modifications include staged (or delayed) construction, varying growth rate in process operating costs as functions of time, incorporation of varying process lives and salvage values, and interest during construction on an other than a straight-line basis.

INTRODUCTION

The purpose of this case is to introduce the concept of the time value of capital and operating costs, within the constraints of USEPA's "Cost-Effectiveness (C-E) Guidelines for Facilities Planning," in evaluating the monetary costs of alternative systems, staged construction, or varying growth rates in process utilization factors.

On the basis of a 25-year planning period, the following factors were incorporated:

(1) An analysis of maintenance and operating (M&O) costs based on year-to-year anticipated growth in expenditures instead of design capacity.

(2) An analysis of the effect of time delayed construction on the inflation-free criteria of the C-E guidelines.

(3) An analysis of the effect of incorporating the salvage value, as defined in the C-E guidelines.

(4) An analysis of the interest-during construction on a basis other than straight line cash flow.

The incorporation of these concepts are necessary, because in evaluating the monetary worth of alternative systems for which Federal funding is sought under PL 92-500, it is necessary that the systems be evaluated on the basis of their relative overall monetary costs. These cost analyses reflect trade-offs between capital and operating expenditures, within the constraints of the planning period.

The changes incorporated in this case also enable the planner or design engineer to evaluate the marginal effect of varying the projected growth rate in M&O costs. These costs usually represent 30 to 80 percent of a project's total estimated cost. Any one of four unique functional relationships can be evaluated. These include fourth degree straight line, exponential, sine-squared, or constant, as well as the constants within these functions.

These changes are incorporated into the Exec Program by:

(1) adding a present worth subroutine for M&O Costs (PREWO),

(2) requiring the user to add some or all of the design input data, and

(3) changing the cost subroutine.

The input data includes DMATX (21 to 27, 1 to 20) for selecting construction time scheduling and M&O growth factors in evaluating capital costs (PWCP), salvage value (SALVG), and M&O costs (POW). The cost subroutine modifications are made to evaluate interest during construction as a non-linear distribution for projects requiring in excess of three years to construct.

Appendix A contains a glossary of new terms added for this analysis.

For comparative purposes this case is designed to run parallel to the base Exec Program. The effect of the C-E guidelines can be evaluated by comparing the appropriate summaries, both of which appear in the printout.

EXAMPLE PROBLEM

The user is required to input up to seven pieces of data DMATX positions 21 to 27 for each of up to 12 process units included. The user has the option to input up to five additional pieces of data in DMATX positions 28 to 32 for any of the included process units. Special considerations for process 20 (i.e. Admin., lab., etc.) which has no required input data, but eight optional data points to modify preset values.

The data must be added in F-format for each of N processes used, (except N=20), as shown in Appendix B. The values are punched onto the data cards following DMATX (20, N) as follows:

(a) DMATX (21,N) = DES (N) = the decision route for determining the rate of growth in percent utilization of M&O costs; Cols. 41-50 on card #12 (see Appendix B).

If DES (N) = 1.0, then $M\&O = A(1,N)[1.+A(2,N) * T - A(3,N) *T^2 + A(4,N) *T^3]$

If DES (N) = 2.0, then $M\&O = A(1,N) * e^{A(2,N) * T}$

If DES (N) = 3.0, then $M\&O = A(1,N) + A(2,N) * \sin^2 (\frac{\pi * T}{2 * T_{Max}})$

If DES (N) = 4.0, then M&O = constant = COSTO (N,1→5)

(b) DMATX (22,N) = A(1,N), Do Not Use, calculated from FUT(N) = COSTO (N) and T = TMAX(N).

(c) DMATX (23,N) = A(2,N) * 1000, required if DES(N) = 1.0, 2.0, or 3.0; Cols. 61-70 on card #13.

(d) DMATX (24,N) = A(3,N) * 1000, required if DES(N) = 1.0, Cols. 71-80 on card #13.

(e) DMATX(25,N) = A(4,N) * 1000, required if DES(N) = 1.0, Cols. 1-10 on card #14.

A(2,N), A(3,N), A(4,N) are automatically set at 0. unless data is otherwise provided.

(f) DMATX(26,N) = TIME(N) = Year process N is placed in service, Time = 1 to 25., Cols. 11-20 on

(g) DMATX(27,N) = TMAX(N) = Year process reaches full capacity, Cols. 21-30 on card #14.

(h) DMATX(28,N) = AIFE(N,1) = Life of each No. 1 sub-process in years, Cols. 31-40 on card #14.

(i) DMATX(29,N) = AIFE(N,2) = Life of each No. 2 sub-process in years, Cols. 41-50 on card #14.

(j) DMATX(30,N) = AIFE(N,3) = Life of each No. 3 sub-process in years, Cols. 51-60 on card #14.

(k) DMATX(31,N) = AIFE(N,4) = Life of each No. 4 sub-process in years, Cols. 61-70 on card #14.

(l) DMATX(32,N) = AIFE(N,5) = Life of each No. 5 sub-process in years, Cols. 71-80 on card #14.

AIFE values are preset at 25.0 years unless data is otherwise provided.

If an entire subroutine process life is to be changed from 25.0 years each of the required number of sub-process (equal to the i-value of the size of the CCOST (N,i) matrix), must be changed.

If the process (or sub-process) life is set so that the units useful life expires before the end of the design period, the program assumes that a duplicate process facility, (or multiple process facilities), will be constructed at the time-adjusted capital cost and placed in service at the time the facility expires.

i.e. Assume $1,000 worth of centrifugation at AIFE = 10 years is required in year TIME = 0., and DESIG = 25.0 years.

Thus, if RI = 5%, then the capital cost is calculated as follows:

CCOST = CAPTAIL COST - SALVAGE VALUE

CCOST = \$1000(1+0.614+0.377) - \$1000 (0.5)(0.295)
= \$1,991 - \$147 = \$1,844

Similarly, the percent utilization and M&O growth curve is assumed to be continuous from the point the initial process life expires.

For the 20th process, (i.e. N=20), Administrative, Laboratory and associated overhead costs, the provisions are made for the inclusion of the following eight pieces of data in positions DMATX(21→26 and 28→29, 20) on cards #8 and 9, APPENDIX B. Each of these design matrix data has a preset internal default value as indicated, if none is provided.

(a) DMATX(21,20) = AMATX = number of different processes used, Cols. 41-50 on card #8, present at 19, (i.e. N=19+1 = 20).

(b) DMATX(22,20) = Inflation rate for capital expenditures in percent per year, Cols. 51-60 on card #8, preset at 0%.

(c) DMATX(23,20) = Average inflation rate for M&O expenditures in percent per year, Cols. 61-70 on card #8, preset at 0%.

(d) DMATX(24,20) = DESIG = Design period in years, Cols. 71-80 on card #8, preset at 25.0 years.

(e) DMATX(25,20) = YER = Maximum number of years for which interest during construction can be assumed to be projected to be expended on a straight line basis, Cols. 1-10 on card #9, preset at 3.0 years.

(f) DMATX(26,20) = TIME(20) = Year process N=20 is placed in service. Cols. 11-20 on card #9, preset at 0 years.

(g) DMATX(27,20) =' Blank not used, Cols. 21-30 on card #9, preset at 0.

(h) DMATX(28,20) = AIFE(20,1) = Life of Number 1 subprocess for N=20, Cols. 31-40 on card #9, preset at 25.0 years.

(i) DMATX(29,20) = AIFE(20,2) = Life of Number 2 subprocess for N=20, Cols. 41-50 on card #9, preset at 25.0 years.

INTERPRETATION OF OUTPUT

The modifications to the Exec Program included in this case are designed to provide the following printouts:

(1) A list of the processes and stream designations used in the run.

(2) A listing of the stream characteristics as used in previous case analyses.

(3) A listing of process characteristics for the basic Exec Program.

(4) A listing of Total Plant Costs for the basic Exec Program

(5) A listing of Total Cost-Effectiveness Plant costs to be compared to the four totals (i.e. TOT, TAMM, TOPER and TOTAL) listed for the total Plant Costs.

(6) A comparative listing of the Case Five C-E Analysis by process, where:

CE M&O represents the present worth M&O costs from this analysis,

COSTO represents the alternative present worth M&O costs at design capacity, from the basic Exec analysis,

CE CAP represents the present worth capital costs allowing for delayed construction,

CCOST represents the present worth capital expenditures not adjusted for delayed construction

SALVG represents salvage value to be subtracted from capital costs when equipment life exceeds the design period,

CE TOT represents total present worth of CE M&O, CE CAP and SALVG for the process,

TOTAL represents comparable total present worth of basic Exec analysis,

TIME represents the year the process was placed in service,

TMAX represents the year process reaches full capacity, DES represents the functional M&O relationship chosen 1, 2, 3, or 4, and

IF represents the N value corresponding to the process designation previously printed.

(7) Listing of input data DMATX(21→32,N) for each of 20 processes.

By modifying the design matrix data, either in the selection of the empirical equation used for the M&O analyses or in the construction scheduling (or life), the effect on the overall relative costs are readily apparent.

From the input data present in Appendix C, the following comparative results, summarized in Appendix D, are obtained:

	Exec Program	CE Analysis
Total Capital, \$ x 10^3	\$6473.00	\$4800.00
Amortized Capital, ¢/1000 gals	13.87	10.29
M&O, ¢/1000 gals.	9.10	7.10
Total Treatment, ¢/1000 gals.	22.97	16.84*

(*including salvage credit)

The difference in total capital between the Exec program and the CE analysis is due to two factors;

(1) delayed construction of various segments of the system up to as much as ten years at 0% inflation,

(2) salvage value credits for processes whose useful lives are projected to extend beyond the end of the period.

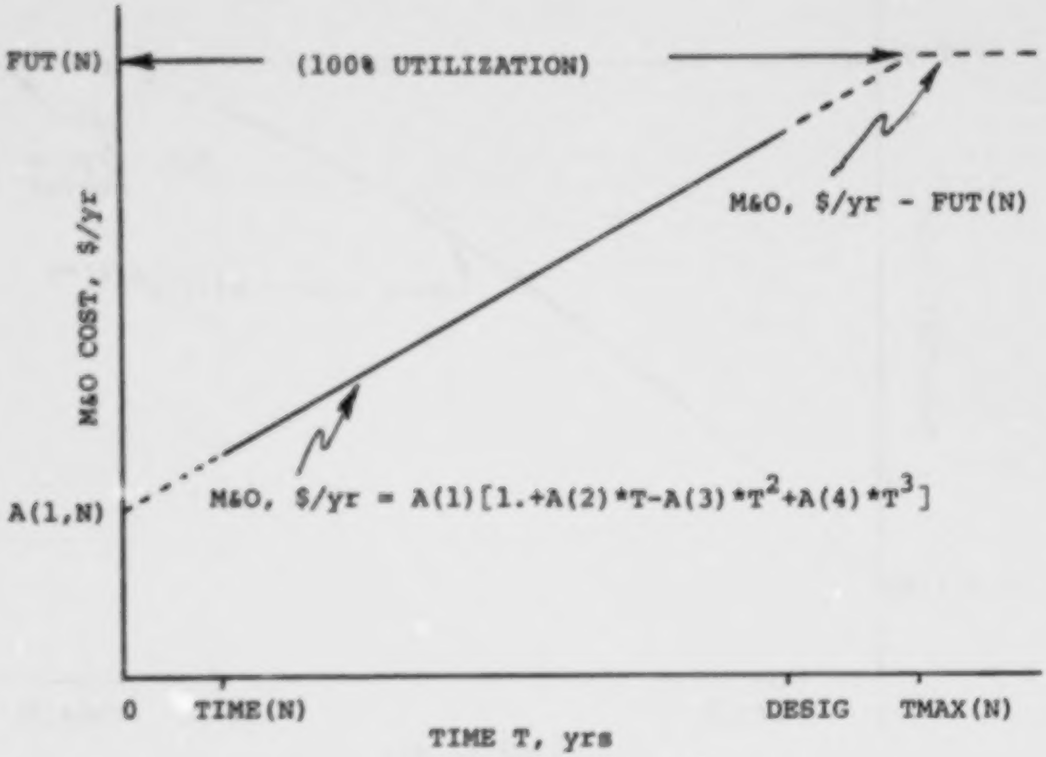
The aeration tanks (AERFS), based on a 35 year salvage credit, or \$93,000 (12.5% of capital), was the most significant. The overall difference being nearly \$1.7-million. A comparable difference is also evident in the amortized capital items. The itemized Exec capital items on Appendix D are the same as those which appear as CCOST in Process Characteristis. If the process in question is placed in service at time 0, the CE Capital expenditures will be nearly equal to the "Exec Cap" value, differening only by the respective ratio values which pro-rate the overhead capital expenditures.

The M&O costs by process in Appendix D are equal to, or less than the Exec M&O costs (COSTO) for each analysis. The degree of difference is a function of the process parameters chosen.

Internally the progarm calculates the A(1,N) value for each process, having one fixed point COSTO (converted to $/year) at 100% utilization (i.e. TMAX year). In addition, values for A(2,N) through A(4,N) will affect the calculation, depending on the processes included.

The overall M&O unit costs cited above reflect this selection of parameters. Care must be exerted to avoid choosing parameters which will generate negative CE - M&O values. Appendix D will alert the user to this unique process or processes that are improperly defined.

Lower M&O unit costs (on a CE basis) plus the amortized capital costs result in a 22.4% decrease in the total treatment cost. If this system were being evaluated against others, changes of this magnitude could effect the "best solution". Similarly these results can be used to evaluate the sensitivity of the M&O costs on the system by varying the parameters used to calculate these present worth values (and subsequently unit cost).



PRESENT WORTH OF M&O COSTS FOR PROCESS N:

$$PW(N),\ \$ = \sum_{T=TIME(N)}^{T=DESIG} [(A(1,N))(1+A(2,N)*T-A(3,N)*T^2+A(4,N)*T^3)*(SPWF(T))]$$

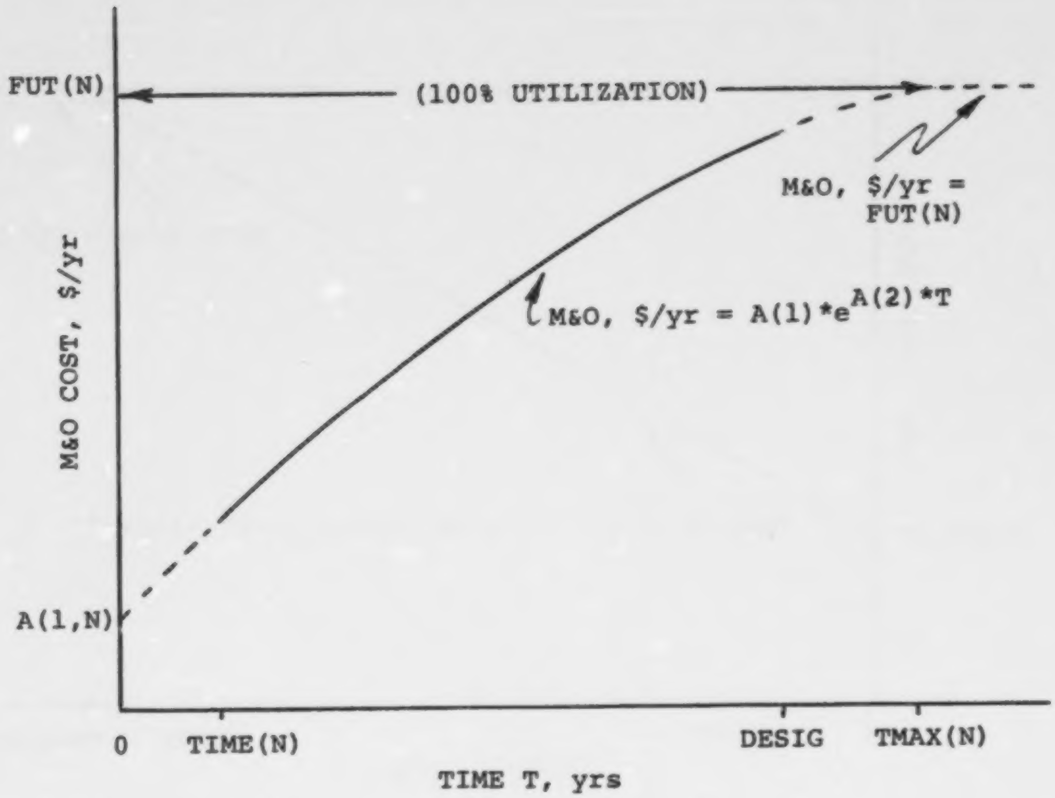
WHERE:

$$A(1,N) = FUT(N)/[1.+A(2,N)*TMAX(N)-A(3,N)*TMAX(N)^2+A(4,N)*TMAX(N)^3]$$

$SPWF(T) = 1./(1.+RI)^T$

RI = RATE OF INTEREST

Figure 1. Maintenance and operating cost curve for DES(N)=1.



PRESENT WORTH OF M&O COST FOR PROCESS N:

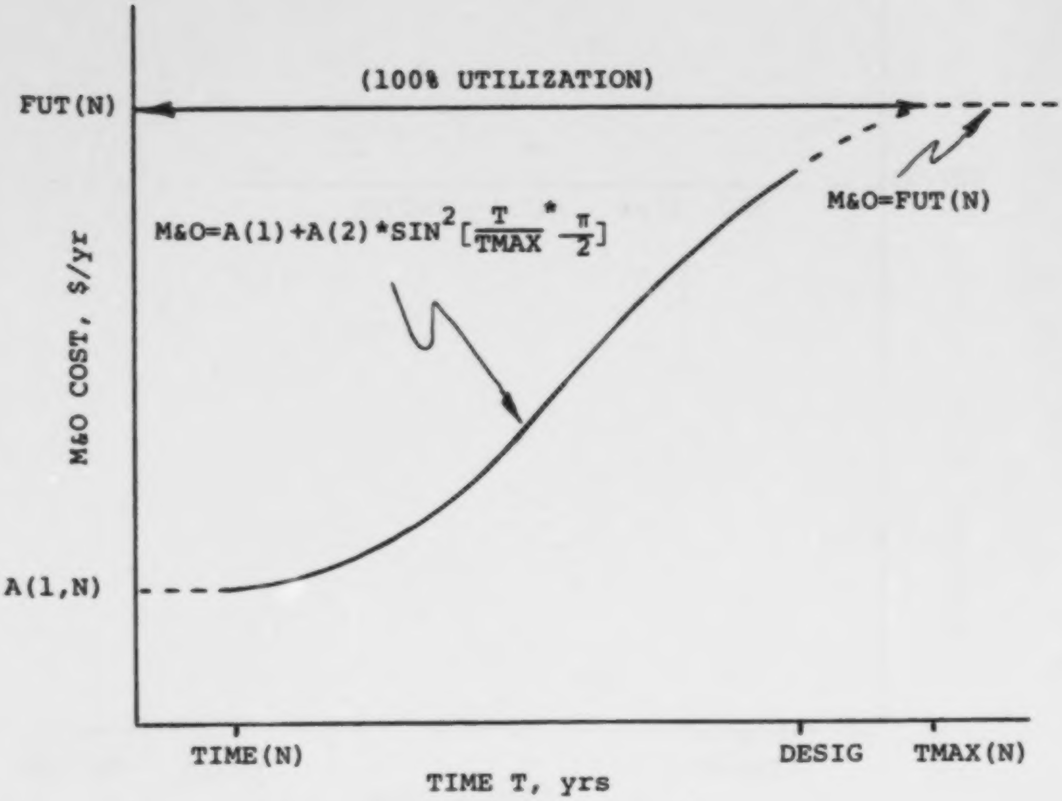
$$\mathrm{PW(N),\ \$} = \sum_{\mathrm{T=TIME(N)}}^{\mathrm{T=DESIG}} \left[(\mathrm{A(1,N)} * e^{\mathrm{A(2,N)*T}}) * (\mathrm{SPWF(T)}) \right]$$

WHERE:

$$\mathrm{A(1,N)} = \mathrm{FUT(N)}/e^{\mathrm{A(2,N)*TMAX(N)}}$$

$$\mathrm{SPWF(T)} = 1./(1.+\mathrm{RI})^{\mathrm{T}}$$

Figure 2. Maintenance and operating cost curve for DES(N)=2.



PRESENT WORTH OF M&O COSTS FOR PROCESS N:

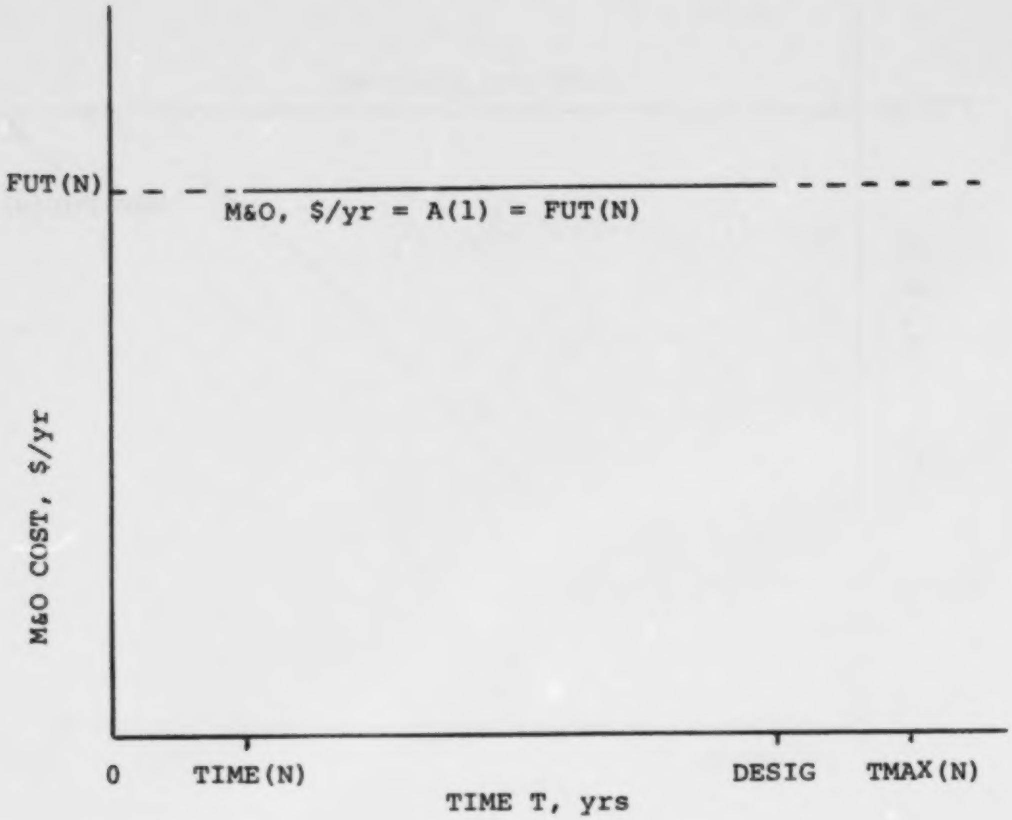
$$PW(N) = \sum_{T=TIME(N)}^{T=DESIG} \left[[A(1,N)+A(2,N)*SIN^2\left(\frac{T}{TMAX(N)}*\frac{\pi}{2}\right)]*(SPWF(T)) \right]$$

WHERE:

$A(1,N) = FUT(N)-A(2,N)$

$SPWF(T) = 1./(1.+RI)^T$

Figure 3. Maintenance and operating cost curve for DES(N)=3.



PRESENT WORTH OF M&O COSTS FOR PROCESS N:

$$PW(N),\ \$ = \sum_{T=TIME(N)}^{T=DESIG} A(1,N)*SPWF(T)$$

WHERE:

$$A(1,N) = FUT(N)/e^{A(3,N)\ x\ TMAX(N)}$$

$$SPWF(T) = 1./(1.+RI)^{T}$$

Figure 4. Maintenance and operating cost curve for DES(N)=4.

Table 1

TOTAL PLANT COST

	EXEC PROGRAM	C-E PROGRAM
TOTAL CAPITAL, \$ x 1000	\$6473.0	\$4800.0
TOTAL AMMORT. CAP., ¢/1000 GAL.	13.87	10.29
TOTAL M&O, ¢/1000 GAL.	9.10	8.09
SALVAGE (CREDIT), ¢/1000 GAL.	(N.A.)	(0.55)
TOTAL TREATMENT, ¢/1000 GAL.	22.97	17.83
CCI	2.257	2.257
WPI	1.675	1.675
RI	0.060	0.060
YRS	25.0	25.0
DHR	4.73	4.73
PCT	0.150	0.150
DA	1000.0	1000.0
CCINT	0.060	0.060
XLAB	1.0	1.0
CKWH	0.02	0.02
RATIO	1.331	1.335
TCAP, \$ x 1000	4863.0	3596.0
YARD, \$ x 1000	681.0	504.0
TCC, \$ x 1000	5544.0	4100.0
XLAND, \$ x 1000	20.0	20.0
ENG, \$ x 1000	459.0	358.0
SUBT1, \$ x 1000	6023.0	4478 0
FISC, \$ x 1000	39.0	34.0
SUBT2, \$ x 1000	6062.0	4512.0
XINT, \$ x 1000	411.0	289.0
ACRE	20.0	20.0
AF	0.078	0.078

Table 2

CASE 5: COST-EFFECTIVENESS ANALYSIS BY PROCESS

TIME(N) YRS.	TMAX(N) YRS.	DES	PROCESS	C-E M&O $x1000	EXEC M&O $x1000	C-E CAP $x1000	EXEC CAP $x1000	SLVG $x1000	C-E TOT $x1000	EXEC TOT $x1000
0	25	1	RWP(15)	$102	$242	$713	$ 710	$ 0	$815	$ 953
1	26	1	PREL(1)	225	261	204	216	2	428	477
5	35	1	PRSET(2)	174	183	305	407	14	465	590
10	50	1	AERFS(3)	185	206	744	1328	93	835	1534
1	30	2	THICK(8)	32	70	176	186	1	206	256
5	30	2	DIG(6)	68	128	468	625	22	515	753
1	30	3	DIG2(21)	173	188	494	522	4	663	710
5	30	3	SHT(16)	83	85	141	188	7	217	273
10	30	3	VACF(7)	273	274	538	961	67	743	1235
5	30	4	MHINC(14)	292	292	579	773	27	845	1066
10	30	4	CHLOR(12)	247	247	151	269	19	379	517
SUB-TOTAL				$1854	$2177	$4513	$6185	$256	$6111	$8364
0	0	4	ADMIN. LAB, ETC.	734	734	287	288	0	1021	1021
TOTAL				$2588	$2911	$4800	$6473	$256	$7132	$9385

APPENDIX A

GLOSSARY OF ADDITIONAL TERMS USED FOR CASE FIVE ANALYSIS

1. System life:

   (a) AIFE (20,5) = life of each subsystem in each of the 20 subroutines.

2. Capital costs:

   (a) FUCAP (20) = Capital cost adjusted by CCI index, $\$ \times 10^3$, working value FUCP.

   (b) PWCP (20) = Present Worth of future capital expenditures delayed in time, $\$ \times 10^3$, working value PCP.

   (c) TOTX = Sum of Capital costs without salvage value adjustment.

3. Maintenance and Operating Costs:

   (a) FUT (20) = Annual M&O cost, \$/yr with system at 100% capacity, $\$ \times 10^3$, working value, FT

   (b) PW (20) = Sum of PMOX's, where PMOX represents the calc. M&O cost (in present worth terms) for each year of operation, $\$ \times 10^3$,

   (c) PWMO = Sum of PW(N) for N processes, $\$ \times 10^3$,

   (d) TOPRX = Total Operating Costs, ¢/thousand gal.

4. Salvage Values:

   (a) SALVG (20) = Salvage Value of capital at end of design period, $\$ \times 10^3$, (Present worth basis),

   (b) TSALV = Sum of SALVG (N) for N processes, ¢/thousand gal.

5. Total Costs:

   (a) TAMMX = Ammortized Capital, ¢/thousand gal.,

   (b) TOTLX = Total Unit Treatment Cost, ¢/thousand gal.,

   (c) TCST = Sum of FUCAP(N) and FUT(N) for each of N processes, $\$ \times 10^3$,

   (d) TOADJ = Sum of PW(N), plus PWCP(N) less SALVG(N) for each of N processes, $\$ \times 10^3$

6. Time Constraints:

(a) TIME(20) = Year process placed in service, T=1 → DESIG

(b) TMAX(20) = Year process reaches full capacity.

(c) DESIGN = Design period, 25 years.

(d) T1 = Working "ΔT" in PREWO subroutine.

(e) T = Working TMAX(N) in PREWO subroutine.

7. Interest Rates:

(a) RI = Amortized interest rate, fraction.

(b) CCINT = Interest rate for the cost of interest during plant construction, fraction.

(c) DMATX(22,20) = Projected annual inflation rate for capital expenditures, percent.

(d) DMATX(23,20) = Projected annual increase in M&O rate scales, percent.

(e) CNT=CNTCP = Difference between RI, amortized interest rate, and DNATX(22,20), inflation factor, fraction.

(f) CNTMO = Difference between RI, and DMATX(23,20), the projected M&O wage growth, fraction.

8. Miscellaneous

(a) DES(N) = Decision variable (input) in choosing one of four M&O formats.

(b) A(1,N) to A(4,N) = Parameters required for M&O functions.

(c) AMATX = N, number of processes used in the analysis.

APPENDIX B

DATA REQUIRED FOR CASE FIVE: COST-EFFECTIVENESS ANALYSIS

Card #	Item	Data							
1	RUNS	No. of Runs (Col. 2)							
2	Title	Title, (Cols. 1-80)							
		Col. 1-10	Col. 11-20	Col. 21-30	Col. 31-40	Col. 41-50	Col. 51-60	Col. 61-70	Col. 71-80
3	SMATX(1→8,1)	Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS
4	SMATX(9→16,1)	TSS	DOC	DNBC	DN	DP	DFM	ALK	DBOD
5	SMATX(17→18,1)	NH_3-N	NO_2-N	----	----	----	----	----	----
6	DMATX(1→8,20)	CCE	WPI	RI	YRS	DHR	PCT	DA	CCINT
7	DMATX(9→10,20)	XLAB	CKWH	----	----	----	----	----	----
8	DMATX(21,20)	----	----	----	----	AMATX	----	----	----
		Col. 1	Col. 3-4	Col. 7-8	Col. 10-15	Col. 20-21	Col. 30-31	Col. 40-41	Col. 50-51
9	PROCESS N	K	N	IPROC	NAME	IS1	IS2	OS1	OS2
		Col. 1-10	Col. 11-20	Col. 21-30	Col. 31-40	Col. 41-50	Col. 51-60	Col. 61-70	Col. 71-80
10	DMATX(1→8,N)	(1,N)	(2,N)	(3,N)	(4,N)	(5,N)	(6,N)	(7,N)	(8,N)
11	DMATX(9→16,N)	(9,N)	(10,N)	(11,N)	(12,N)	(13,N)	(14,N)	(15,N)	(16,N)
12	DMATX(21→24,N)	----	----	----	----	DES(N)	----	A(2,N)	A(3,N)
13	DMATX(25→27,N)	A(4,N)	TIME(N)	TMAX(N)	----	----	----	----	----

Cards 9-13 are repeated for each process used, except MIX and SPLIT, where only card 9 is required.

The last card in the data deck should have a 9 in column one.

Most data is input in F format, except for Card 1 (I format), Card 2 (A format), and each process card (Card 9 - I format, except for columns 10-15 - A format).

APPENDIX C

DATA USED IN CASE FIVE EXAMPLE

Card #	Item	Data							
		Col. 2							
1	RUNS	1							
2	Title	10 MGD EXECUTIVE PROGRAM STD. TEST #1 Jan. 1975 $$							
		Col. 1-10	Col. 11-20	Col. 21-30	Col. 31-40	Col. 41-50	Col. 51-60	Col. 61-70	Col. 71-80
3	SMATX(1→8,1)	10.0	105.0	30.0	10.0	2.0	30.0	140.0	224.0
4	SMATX(9→16,1)	254.0	43.0	11.0	19.0	4.0	500.0	250.0	60.0
5	SMATX(17→18,1)	15.0	0.0	----	----	----	----	----	----
6	DMATX(1→8,20)	2.257	1.675	.06	25.0	4.73	.15	1000.0	.06
7	DMATX(9→11,20)	1	.02	1.0	----	----	----	----	----
* 8	DMATX(21,20)	----	----	----	----	11.0	----	----	----
**	(card omitted)								
		Col. 1	Col. 3-4	Col. 7-8	Col. 10-15	Col. 20-21	Col. 30-31	Col. 40-41	Col. 50-51
9	PROCESS, N=1	0	1	15	RWP	1	0	2	0
		Col. 1-10	Col. 11-20	Col. 21-30	Col. 31-40	Col. 41-50	Col. 51-60	Col. 61-70	Col. 71-80
10	DMATX(1→8,N)	30.0	----	----	----	----	----	----	----
11	DMATX(9→16,N)	----	----	----	----	----	----	----	1.0
12	DMATX(21→24,N)	----	----	----	----	1.0	----	500.0	20.0
13	DMATX(25→27,N)	1.0	0.	25.0	----	----	----	----	----
		Col. 1	Col. 3-4	Col. 7-8	Col. 10-15	Col. 20-21	Col. 30-31	Col. 40-41	Col. 50-51
14	PROCESS, N=2	0	2	1	PREL	2	0	3	0
		Col. 1-10	Col. 11-20	Col. 21-30	Col. 31-40	Col. 41-50	Col. 51-60	Col. 61-70	Col. 71-80
15	DMATX(1→8,N)	1.0	----	----	----	----	----	----	----
16	DMATX(9→16,N)	----	----	----	----	----	----	----	1.0
17	DMATX(21→24,N)	----	----	----	----	1.0	----	500.0	40.0
18	DMATX(25→27,N)	1.0	1.0	26.0	----	----	----	----	----
		Col. 1	Col. 3-4	Col. 7-8	Col. 10-15	Col. 20-21	Col. 30-31	Col. 40-41	Col. 50-51
19	PROCESS, MIX	0	0	4	MIX	3	19	4	0
20	PROCESS, N=3	0	3	2	PRSET	4	0	5	7
		Col. 1-10	Col. 11-20	Col. 21-30	Col. 31-40	Col. 41-50	Col. 51-60	Col. 61-70	Col. 71-80
21	DMATX(1→8,N)	0.5	400.0	14.0	----	----	----	----	----
22	DMATX(9→16,N)	----	----	----	----	----	----	1.0	1.2
23	DMATX(21→24,N)	----	----	----	----	1.0	----	5.0	1.0
24	DMATX(25→27,N)	0.05	5.0	35.0	----	----	----	----	----
		Col. 1	Col. 3-4	Col. 7-8	Col. 10-15	Col. 20-21	Col. 30-31	Col. 40-41	Col. 50-51
25	PROCESS, N=4	0	4	3	AERFS	5	0	6	0
		Col. 1-10	Col. 11-20	Col. 21-30	Col. 31-40	Col. 41-50	Col. 51-60	Col. 61-70	Col. 71-80
26	DMATX(1→8,N)	13.0	2000.0	20.0	1.0	1.0	0.5	3.0	700.0
27	DMATX(9→16,N)	30.0	0	----	----	1.2	1.0	1.0	1.2
28	DMATX(21→24,N)	----	----	----	----	1.0	----	5.0	1.0
29	DMATX(25→27,N)	.05	-10.0	50.0	----	----	----	----	----

* DMARX(22-24,20) optional.

** Card no. 9 with DMATX(25-29,20) optional data omitted. Card must be included.

APPENDIX C
(Cont.)

	Col. 1	Col. 3-4	Col. 7-8	Col. 10-15	Col. 20-21	Col. 30-31	Col. 40-41	Col. 50-51
30 PROCESS, SPLIT	0	0	5	SPLIT	6	0	25	24
31 PROCESS, MIX	0	0	4	MIX	7	8	9	0

	Col. 1	Col. 3-4	Col. 7-8	Col. 10-15	Col. 20-21	Col. 30-31	Col. 40-41	Col. 50-51
32 PROCESS, N=5	0	5	8	THICK	9	24	10	20

	Col. 1-10	Col. 11-20	Col. 21-30	Col. 31-40	Col. 41-50	Col. 51-60	Col. 61-70	Col. 71-80
33 DMATX(1→8,N)	0.95	50000.0	700.0	8.0	----	----	----	----
34 DMATX(9→16,N)	----	----	----	----	----	----	----	1.5
35 DMATX(21→24,N)	----	----	----	----	2.0	----	40.0	----
36 DMATX(25→27,N)	----	1.0	30.0	----	----	----	----	----

	Col. 1	Col. 3-4	Col. 7-8	Col. 10-15	Col. 20-21	Col. 30-31	Col. 40-41	Col. 50-51
37 PROCESS, N=6	0	6	6	DIG	10	0	11	0

	Col. 1-10	Col. 11-20	Col. 21-30	Col. 31-40	Col. 41-50	Col. 51-60	Col. 61-70	Col. 71-80
38 DMATX(1→8,N)	15.0	30.0	----	----	----	----	----	----
39 DMATX(9→16,N)	----	----	----	----	----	----	----	1.3
40 DMATX(21→24,N)	----	----	----	----	2.0	----	40.0	----
41 DMATX(25→27),N)	-----	5.0	30.0	----	----	----	----	----

	Col. 1	Col. 3-4	Col. 7-8	Col. 10-15	Col. 20-21	Col. 30-31	Col. 40-41	Col. 50-51
42 PROCESS, N=7	0	7	21	DIG2	11	0	12	21

	Col. 1-10	Col. 11-20	Col. 21-30	Col. 31-40	Col. 41-50	Col. 51-60	Col. 61-70	Col. 71-80
43 DMATX(1→8,N)	0.81	50000.0	15.0	----	----	----	----	----
44 DMATX(9→16,N)	----	----	----	----	----	----	----	1.0
45 DMATX(21→24,N)	----	----	----	----	3.0	----	500.0	----
46 DMATX(25→27,N)	----	1.0	30.0	----	----	----	----	----

	Col. 1	Col. 3-4	Col. 7-8	Col. 10-15	Col. 20-21	Col. 30-31	Col. 40-41	Col. 50-51
47 PROCESS, N=8	0	8	16	SHT	12	0	13	0

	Col. 1-10	Col. 11-20	Col. 21-30	Col. 31-40	Col. 41-50	Col. 51-60	Col. 61-70	Col. 71-80
48 DMATX(1→8,N)	15.0	----	----	----	----	----	----	----
49 DMATX(9→16,N)	----	----	----	----	----	----	----	1.0
50 DMATX(21→24,N)	----	----	----	----	3.0	----	500.0	----
51 DMATX(25→27,N)	----	5.0	30.0	----	----	----	----	----

	Col. 1	Col. 3-4	Col. 7-8	Col. 10-15	Col. 20-21	Col. 30-31	Col. 40-41	Col. 50-51
52 PROCESS, N=9	0	9	7	VACF	13	0	14	23

	Col. 1-10	Col. 11-20	Col. 21-30	Col. 31-40	Col. 41-50	Col. 51-60	Col. 61-70	Col. 71-80
53 DMATX(1→8,N)	4.9	3.5	200.0	1.0	42.0	176.0	.064	.0125
54 DMATX(9→16,N)	15.0	.33	----	----	----	----	----	1.0
55 DMATX(21→24,N)	----	----	----	----	3.0	----	600.0	----
56 DMATX(25→27,N)	----	10.0	30.0	----	----	----	----	----

	Col. 1	Col. 3-4	Col. 7-8	Col. 10-15	Col. 20-21	Col. 30-31	Col. 40-41	Col. 50-51
57 PROCESS, MIX	0	0	4	MIX	20	21	22	0
58 PROCESS, MIX	0	0	4	MIX	22	23	19	0

APPENDIX C
(Cont.)

	Col. 1	Col. 3-4	Col. 7-8	Col. 10-15	Col. 20-21	Col. 30-31	Col. 40-41	Col. 50-51
59 PROCESS, N = 10	0	10	14	MHIHC	14	0	15	0
	Col. 1-10	Col. 11-20	Col. 21-30	Col. 31-40	Col. 41-50	Col. 51-60	Col. 61-70	Col. 71-80
60 DMATX(1+8,N)	2.0	1.0	35.0	5.0	0.	10000.0	1.0	0.3
61 DMATX(9+16,N)	0.97	----	----	----	----	----	----	1.0
62 DMATX(21+24,N)	----	----	----	----	4.0	----	----	----
63 DMATX(25+27,N)	----	5.0	30.0	----	----	----	----	----
	Col. 1	Col. 3-4	Col. 7-8	Col. 10-15	Col. 20-21	Col. 30-31	Col. 40-41	Col. 50-51
64 PROCESS, N=11	0	11	12	CHLOR	25	.0	26	0
	Col. 1-10	Col. 11-20	Col. 21-30	Col. 31-40	Col. 41-50	Col. 51-60	Col. 61-70	Col. 71-80
65 DMATX(1+8,N)	8.0	30.0	220.0	2.5	180.0	----	----	----
66 DMATX(9+16,N)	----	----	----	----	----	1.2	1.2	1.5
67 DMATX(21+24,N)	----	----	----	----	4.0	----	----	----
68 DMATX(25+27,N)	----	10.0	30.0	----	----	----	----	----
	Col. 1							
69	9	0	0	0	0	0	0	0

APPENDIX D

SUMMARY OF TEST CASE RESULTS

ANALYSIS BY PROCESS, ($ x 1000)

PROCESS	TIME YR	TMAX YR	DES	CE M&O	EXEC M&O	CE CAP	CE SALVG	EXEC CAP	CE TOTAL	EXEC TOTAL
RWP(15)	0	25	1	$102	$242	$713	$ 0	$ 710	$815	$ 953
PREL(1)	1	26	1	225	261	204	2	216	428	477
PRSET(2)	5	35	1	174	183	305	14	407	465	590
AERFS(3)	10	50	1	185	206	744	93	1328	835	1534
THICK(8)	1	30	2	32	70	176	1	186	206	256
DIG(6)	5	30	2	68	128	468	22	625	515	753
DIG2(21)	1	30	3	173	188	494	4	522	663	710
SHT(16)	5	30	3	83	85	141	7	188	217	273
VACF(7)	10	30	3	273	274	538	67	961	743	1235
MHINC(14)	5	30	4	292	292	579	27	773	845	1066
CHLOR(12)	10	30	4	247	247	151	19	269	379	517
SUB-TOTAL				$1854	$2177	$4513	$256	$6185	$6111	$8364
Admin. Lab. etc.	0	0	4	734	734	287	0	288	1021	1021
TOTAL				$2588	$2911	$4800	$256	$6473	$7132	$9385

CASE VI WORKSHOP

ADDITION OF A GRANULAR BED FILTRATION SUBROUTINE TO THE EXEC PROGRAM

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ABSTRACT

A subroutine is described which can be included in the Exec Program and used to estimate the performance and cost of a wastewater treatment system which includes a granular bed filtration process. The subroutine uses filter design and operating conditions such as the filtration rate, media size distributions and influent SS concentration to calculate the filter plan area requirement when the filter run length is limited by the headloss constraint. The plan area requirement is the basis for determining the costs associated with the filtration process. Details of how to incorporate the subroutine into the Exec Program and sample results are described.

INTRODUCTION

The importance of granular media filtration in the treatment of wastewater has risen dramatically with the implementation of the Federal Water Pollution Control Act Amendments of 1972. Lykins and Smith (1) have reported that over 1500 treatment plants will apply tertiary filtration in order to meet current water quality standards. An equivalent number of plants will be required to meet anticipated standards by 1985.

The Exec Program in its present form does not contain a unit process subroutine for granular media filtration. The purpose of this case study is to outline the derivation of such a subroutine and to describe how it is incorporated into the existing Exec Program.

FILTRATION SUBROUTINE

Flow Diagram

Figure 1 shows the general configuration of the filtration system used in this analysis. Note that while this is a typical system, there are a number of variations of this general scheme in use. For example, the backwash water holding tank is sometimes omitted or replaced by a clarifier. Equalization tanks are used in some installations prior to the filters. In some cases, a separate wet well may be used in place of the chlorine contact unit as a source of backwash water.

Design Equations

The approach used in this analysis was to base the capital cost of the filters on the total plan area of the filter beds (A). Ives (2) has evaluated this approximation and reported that it is reasonable. Huang and Baumann (3) have also described its use.

The magnitude of A can be determined using the following equation,

$$A = \frac{Q}{NWP}, \qquad (1)$$

where Q is the design raw wastewater flow rate, and NWP is the net filtered water production per unit plan area per unit time.

The net filtered water production per day is calculated by subtracting the backwash volume per run from the filtered water production per run (using a per unit plan area basis) and then multiplying this result by the total number of filter runs per day. In equation form this is,

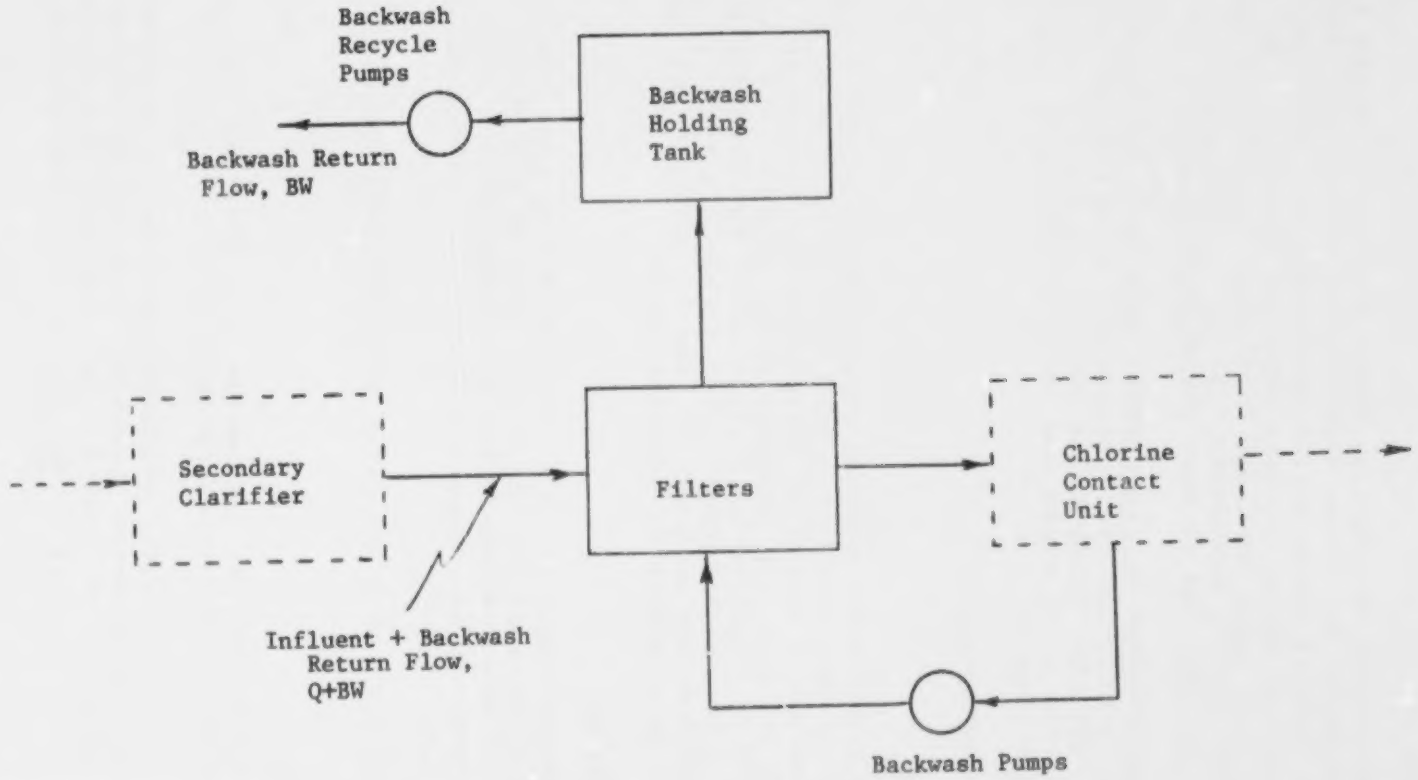
Backwash
Recycle
Pumps
Backwash Return
Flow, BW
Backwash
Holding
Tank
Secondary
Clarifier
Filters
Chlorine
Contact
Unit
Influent + Backwash
Return Flow,
Q+BW
Backwash Pumps

Figure 1. Schematic Diagram of the Filtration Process

$$NWP\ (gal/ft^2/day) = WP = (QB)\ (TB)\ \frac{1440}{\frac{WP}{QF} + TB}\ , \quad (2)$$

where,

WP is the filtered water production per filter run (gal/ft^2),

QB is the average backwash flowrate (gpm/ft^2)

TB is the filter down-time per backwash (min), and

QF is the filtration rate (gpm/ft^2).

The filtered water production per filter run (WP) can be determined using an expression which is based on a simple mass balance across the filter bed. This equation is,

$$WP\ (gal/ft^2) = \frac{F(FK)(D)}{E(CO)(NF)} \sum_{I=1}^{NF} \log \frac{\Delta H}{[AK(I)][D][QF]} \quad (3)$$

where,

FK is an experimentally determined coefficient proportional to the mass density of the deposit within the filter ($gal\ mg/ft^3 l$)

F is a fraction between 0 and 1, the magnitude of which depends on the distribution of deposit within the filter bed,

E is the fractional removal efficiency of SS across the filter bed,

CO is the steady state influent suspended solids, concentration (mg/l),

NF is the number of equal depth layers used in analyzing the filter bed,

D is the overall depth of the filter bed (ft),

ΔH is the overall terminal headloss (ft of water), and

AK(I) is the clean bed headloss across layer I per unit layer depth and per unit filtration rate (ft^2/gpm).

The derivation of Eq (3) and methods to determine FK and F have been described by Letterman (4).

The total backwash volume per day, BW, is calculated by multiplying the backwash volume per filter run by the number of filter runs per filter per day, i.e.,

$$\text{BW (mgd)} = [A]\ [(QB)(TB)]\ \frac{1440}{\frac{WP}{QF} + TB}\ (10^{-6}) \qquad (4)$$

The mean concentration of suspended solids (SS) in the recycled backwash water is given by,

$$SS = \frac{(WP)(E)(CO)}{(QB)(TB)} \qquad (5)$$

The volume of the backwash water holding tank, $\mathcal{V}$, (see Figure 1) can be determined by assuming that its volume should be equal to the volume of water produced by the backwashing of all the filter beds in rapid succession. This is given by,

$$\mathcal{V} = [A]((QB)(TB)] \qquad (6)$$

The flowrate capacity, BP, of the backwash pumps is given by,

$$BP = (AB)\ [\tfrac{A}{M}], \qquad (7)$$

where M is the number of individual equal-sized filter beds in the system.

The flowrate capacity of backwash recycle pumps is simply the backwash recycle flowrate, BW, as given by Eq. (4).

Design Equations - Assumptions Used

The following assumptions were made in deriving the design equations.

1. The filtered water production per filter run is determined by the overall headloss constraint and not by effluent quality.
2. The suspended solids removal efficiency is constant during the filter run. Extensive field studies by FitzPatrick and Swanson (5) support both of the above assumptions.
3. The filtration rate is constant during the filter run. This type of operation is common in wastewater filtration. However, the equations can be modified and used

to evaluate a system with declining rate of filters.

4. The system is operating under steady state conditions, i.e., the concentration, physical/chemical characteristics, etc. of the filter influent SS are constant with time.

   Filtration takes place within the media, i.e., there is negligible cake formation on top of the bed. This is also supported by FitzPatrick and Swanson (5) who have observed that under most field conditions, where dual or multi media beds are used, the suspended solids penetrate the top surface of the bed.

Cost Equations

The cost equations used in this analysis are based on a set of expressions developed by Van Note *et al* (6) for a dual media filtration system receiving secondary effluent. The system used in Van Note's *et al.* cost analysis is essentially the same as the one shown in Figure 1. The equations developed lump together the individual units in the system (pumps, filters, holding tank) and express their overall cost as a function of the flowrate. These equations have been converted from a flowrate to a unit filter plan area basis using the filtration rate which Van Note *et al* assumed in their analysis. An additional equation has been included for the backwash electrical costs. These equations are listed below.

1. Capita cost, C (in January, 1971 dollars) of the filter system including backwash water storage and all pumps and piping

   $$C = 6378.1\ A^{0.66}; \qquad (8)$$

2. Base man-hour requirement, BMH (in man-hours/year),

   $$BMH = \frac{A}{0.1224 + 0.00058A}; \qquad (9)$$

3. Base material costs, BMC (in January, 1971 dollars/years), $451.33\ A^{0.68}$ (10)

4. Variable O & M costs (excl. backwashing electrical costs), COMV (in ¢/1000 gal.),

   $$COMV = BMC \left(\frac{WPI}{112.2}\right) \left(\frac{1}{3650\ Q}\right) \qquad (11)$$

   where WPI is the wholesale price index of industrial commodities for the year to be used as a basis for costs.

5. Fixed O & M costs, COMF (in ¢/1000 gal.)

$$COMF = (BMH)\ (MHR)\ \frac{1}{3650\ Q} \qquad (12)$$

where MHR is the labor rate in $/man-hour.

6. Electricity cost for backwashing, ECBW (in ¢/1000 gal.)

$$ECBW = 1146\ \frac{(BW)\ (HD)\ (CKWH)}{(EEF)}\ \left(\frac{1}{3650\ Q}\right) \qquad (13)$$

where HD is the total dynamic pumping head in feet (including backwash and recycle)

efficiency (decimal) and CKWH is the per unit KW hour electrical power costs ($/Kw-hr).

Cost Equations - Assumptions Used

The following assumptions were used in adapting and applying Van Note's *et al.* (6) cost equations.

1. It was assumed that the cost of the overall filtration system can be determiend using the filter plan area as the critical design parameter. In most cases this assumption is made reasonable by the fact that the filter beds are the dominant cost item in the filtration system. As shown by Equations (4), (6) and (7), the sizes of other components in the system (backwash holding tank, backwash and recycle pumps) are proportional to the filter plan area, however, they are also a function of design parameters such as the backwash rate and duration, and the number of filter beds in the system. Therefore, for example, if the objective is to analyze the effect of the backwash rate on the treatment system performance and cost, it may be necessary to use individual cost equations for the system components rather than the more comprehensive equations shown.

2. The use of the filter plan area as the critical design parameter implies that the cost per unit area of filter is a function only of the size of the plant. Therefore, although it is possible to analyze the effect of the terminal headloss and overall depth of the filter bed on system cost, caution should be used in varying these parameters as it is likely they determine to some extent the cost per unit plan area of filter bed A more detailed cost breakdown for the filter beds would be necessary to correct this shortcoming.

PROGRAMMING

Incorporating the Design and Cost Equations in the Executive Program

The design and cost equations described in the previous sections were combined in a filtration(FILT) subroutine (see Appendix A). A computational flow chart for the FILT subroutine is given in Figure 2 . A symbol for the process with input and output stream designations is shown in Figure 3 Listings of the contents of DMATX and OMATX for the FILT subroutine are given in Tables 1 and 2. Modifications were necessary in the EXECMAIN program and the PRINT subroutine in order to call the filtration subroutine and to print the new input and output quantities. The specifics of these modifications are described in the following section.

Modifications of the original program.

1. EXECMAIN - A listing of the modified portions of EXECMAIN is given in Appendix B. Two statements have been added to the original program so that the FILT subroutine is called by EXECMAIN. In addition the GO TO statement was modified. Both changes are shown in Appendix B.

2. Subroutine PRINT - A listing of the modified portions of subroutine PRINT is given in Appendix C. Five statements, numbered 230 to 240 have been added to the original subroutine so that the decision and output matrix parameters listed in Tables 1 and 2 are printed.

EXAMPLE RESULTS

The treatment system diagrammed in Figure 4 was used to illustrate the application of the FILT subroutine. The configuration shown is a typical activated sludge system with tertiary granular bed filtration. The backwash water in this case is drawn from the chlorine contact unit and recycled after use to a point just before the preliminary operations. Also shown in Figure 4 are the recycle loop numbers (K) and the process stream numbers.

In these examples it was assumed that the proportionality constant, FK, in Eq. (3) is equal to 5.7×10^4 gal-mg/ft^3-1. This value was determined by Letterman (7) in a pilot plant study of the filtration of clay suspensions treated with cationic polyelectrolytes. It is possible that the value of FK for secondary effluent particulate matter is significantly different. However, a rough test of the above value using data on biological solids capture per unit increase in headloss compiled by Baumann and Cleasby (8) suggests that it is of the correct order of

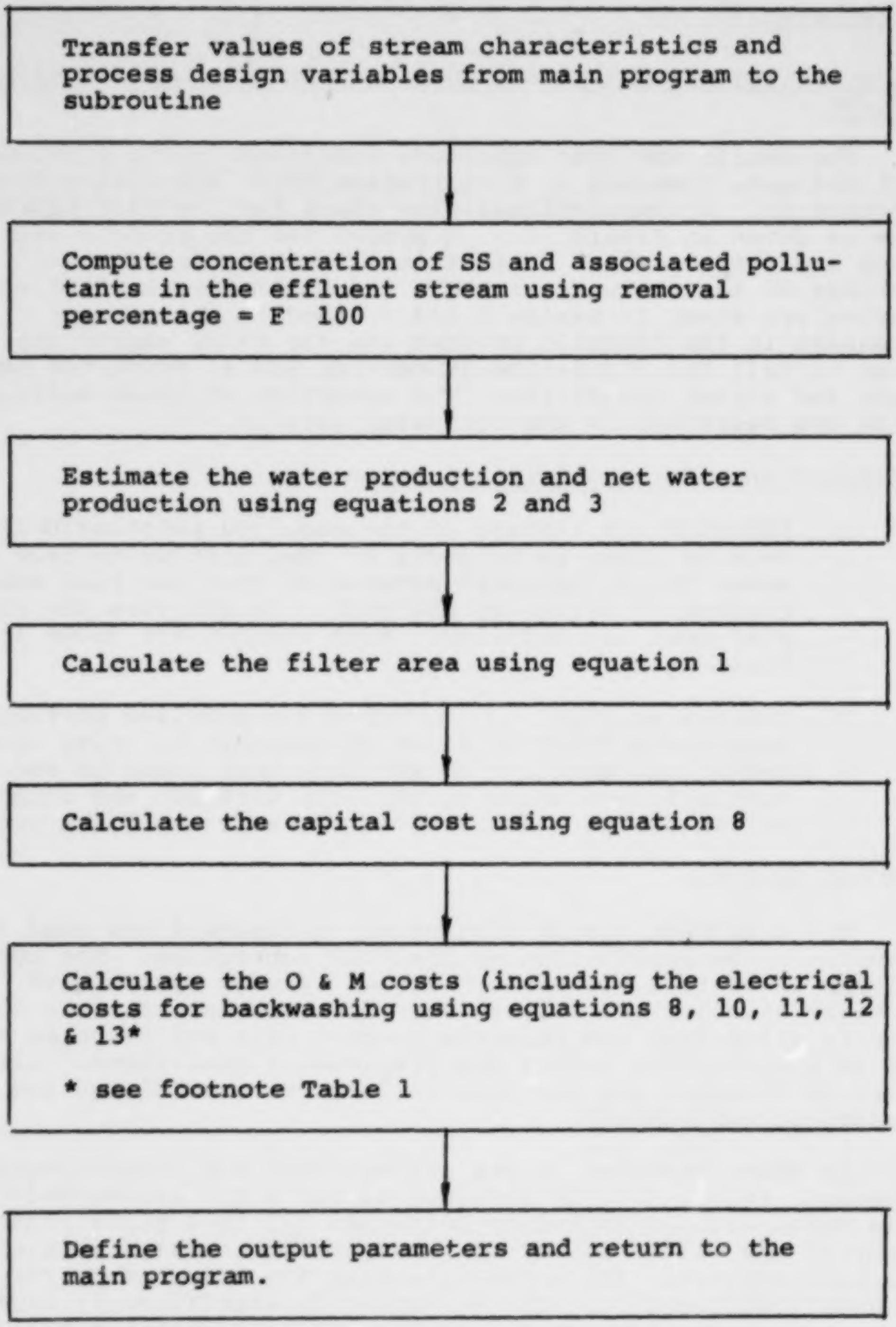
Transfer values of stream characteristics and process design variables from main program to the subroutine
Compute concentration of SS and associated pollutants in the effluent stream using removal percentage = E 100
Estimate the water production and net water production using equations 2 and 3
Calculate the filter area using equation 1
Calculate the capital cost using equation 8
Calculate the O & M costs (including the electrical costs for backwashing using equations 8, 10, 11, 12 & 13*
* see footnote Table 1
Define the output parameters and return to the main program.

Fig. 2 Computational Flow Chart for the Filtration Subroutine

Granular Bed Filtration
(FILT)

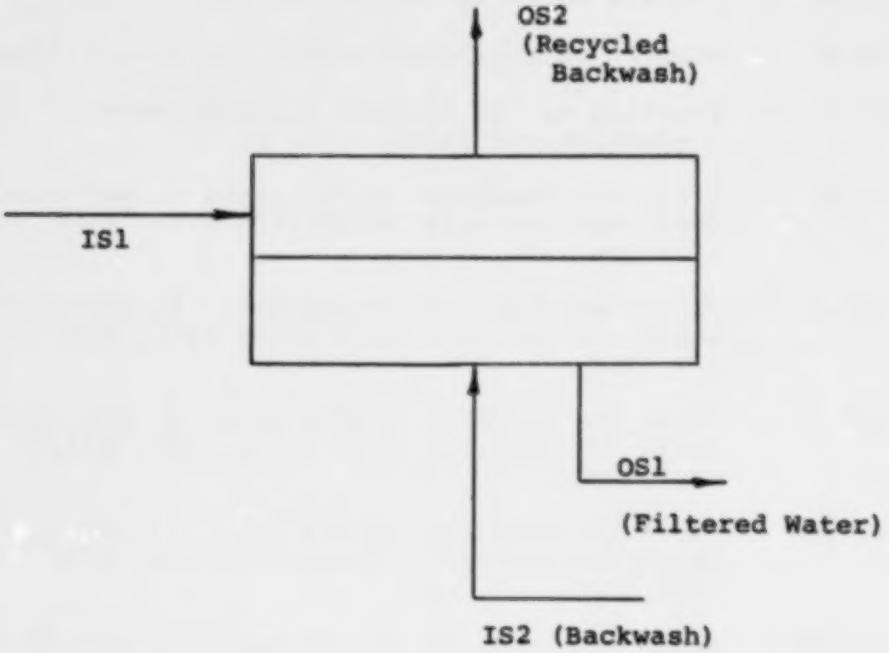
OS2
(Recycled
Backwash)
IS1
OS1
(Filtered Water)
IS2 (Backwash)

Figure 3
Granular Bed Filtration Process
Symbol with Stream Designations

Table 1. Listing of the contents of DMATX for the FILT subroutine.

DMATX (1,N) = Fractional suspended solids removal efficiency,E.

DMATX (2,N) = Downtime per backwash, TB (min).

DMATX (3,N) = Filtration rate, QF (gpm/ft^2).

DMATX (4,N) = Overall terminal headloss, ΔH (ft of water).

DMATX (5,N) = Overall depth of the filter bed, D (ft)

DMATX (6,N) = Deposit density coefficient, FK (gal/ft^3/mg/l).

DMATX (7,N) = Fraction of the maximum filtered water production per filter run, F.

DMATX (8,N) = Clean bed headloss across layer 6, per unit depth and per unit filtration rate, K(6) (ft^2/gpm).

DMATX (9,N) = Clean bed headloss across layer 5, per unit depth and per unit filtration rate, K(5) (ft^2/gpm).

DMATX (10,N) = Clean bed headloss across layer 4, per unit depth and per unit filtration rate, K(4) (ft^2/gpm).

DMATX (11,N) = Clean bed headloss across layer 3, per unit depth and per unit filtration rate, K(3) (ft^2/gpm).

DMATX (12,N) = Clean bed headloss across layer 2, per unit depth and per unit filtration rate, K(2) (ft^2/gpm).

DMATX (13,N) = Clean bed headloss across layer 1, per unit depth and per unit filtration rate, K(1) (ft^2/gpm).

DMATX (14,N) = Backwash rate, QB (gpm/ft^2).

DMATX (16,N) = Excess capacity factor, ECF.

*DMATX (17,N) = Total dynamic pumping head for backwash and recycle, HD (ft of water)

*DMATX (18,N) = Fractional overall pump efficiency for backwash and recycle, EFF.

Table 1. Continued

* Note: The inclusion of DMATX (17,N) and DMATX (18,N) in the FILT subroutine would have exceeded the 16 row capacity of the DMATX as provided in the main program. Changes could have been made in the program to increase the DMATX capacity, however, since hand calculations showed that the ECBW is insignificant compared to the other O & M costs, the ECBW calculation (Eq. (13)) was omitted from the subroutine. Anytime a new subroutine is added to the EXEC program care should be taken not to exceed the capacity of the common statements such as DMATX, OMATX or SMATX. However, the capacity of these statements can be increased by further modifications to EXECMAIN.

Table 2. Listing of the contents of OMATX for the FILT subroutine.*

OMATX (1,N) = Filtered water production per filter run, WP (gal/ft^2)

OMATX (2,N) = Filter plan area, A (ft^2)

OMATX (3,N) = Net filtered water production per filter run, NWP (gal/ft^2)

OMATX (4,N) = Fractional suspended solids removal efficiency, E.

* See Footnote Table 1

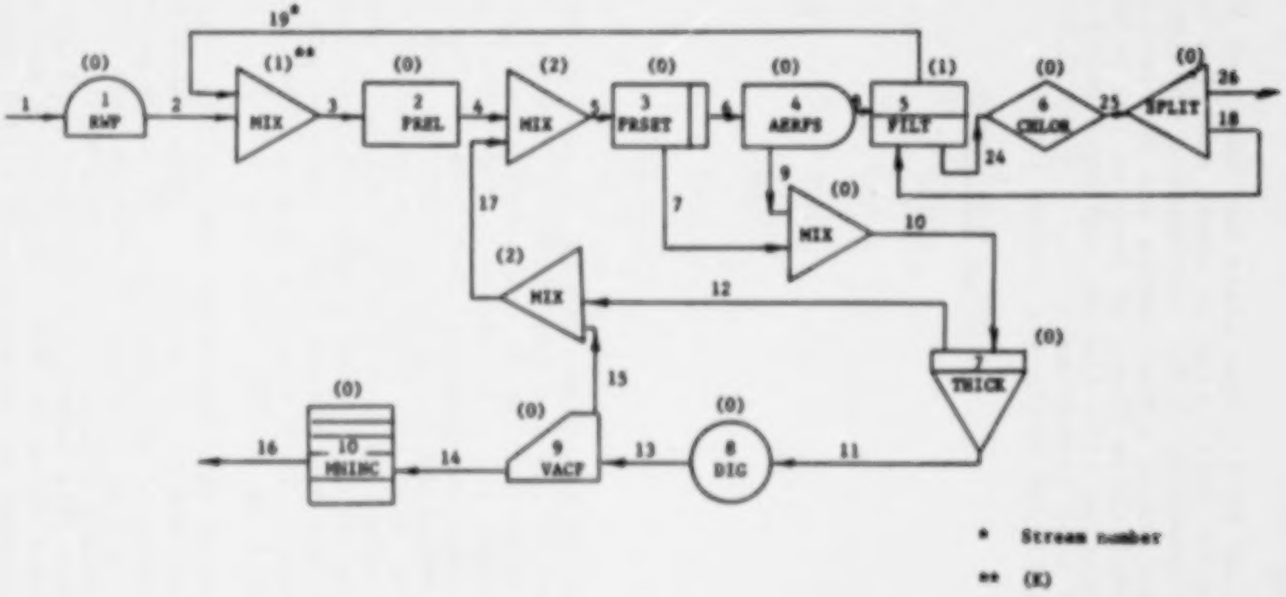
1
(0)
1
RWP
2
19*
(1)**
MIX
3
(0)
2
PREL
4
(2)
MIX
5
(0)
3
PRSET
6
(0)
4
AERPS
(1)
5
FILT
(0)
6
CHLOR
23
(0)
SPLIT
26
18
24
9
7
(0)
MIX
10
17
(2)
MIX
12
(0)
7
THICK
15
(0)
10
MHINC
16
14
(0)
9
VACF
13
(0)
8
DIG
11
* Stream number
** (K)

Figure 4. Process Configuration

magnitude. Research to derive and confirm appropriate values of FK is underway (9).

The values of AK(I), the clean bed headloss per unit depth and unit filtration rate, used in these examples were those determined by DiDomenico (10). DiDomenico conducted pilot plant experiments using a dual media bed consisting of a layer of anthracite coal three times as deep as the underlying sand layer. The effective size (in mm) and uniformity coefficient of the coal and sand layers were 1.2, 1.6 and 0.5, 1.4 respectively. The values of AK(I) are listed below:

Layer I =	AK(I) (ft^2/gpm)
1 (top)	0.030
2	0.030
3	0.028
4	0.038
5	0.140
6	0.180

The deposit distribution factor, F, was assumed to be 0.5. A method for estimating the magnitude of F using the layer by layer headloss distribution at run termination has been described by Letterman (4). In general, F is equal to 1, its maximum value, when the terminal headloss is distributed evenly across all the equal depth layers of the bed and is equal to its minimum value when the headloss is localized in one stratum of the bed. FitzPatrick and Swanson (5) have observed that in the filtration of activated sludge effluent using dual media filters most of the deposition takes place in the top several inches of the coal. This suggests that in this type of system the magnitude of F is in the range 0.2 to 0.5.

It was assumed that the suspended solids removal efficiency across the filter bed is 70 percent. This value is near the middle of the range of efficiencies (50 to 90 percent) reported by Kriessl (11) and by FitzPatrick and Swanson (5) for the filtration of secondary effluent using dual media filters. It was also assumed that this removal efficiency applies to the removal of the particulate forms of BOD, phosphorous and nitrogen. It is notable that a number of investigators (3,12) have reported that the SS removal efficiency of granular bed filters treating secondary effluent is essentially independent of the magnitudes of design and operational parameters such as the filtration rate, media size distributions and influent SS concentration.

Typical values were assumed for the other operational parameters needed in the filter design equations. These include

1. Terminal headloss, $\Delta H = 7.2$ ft of water
2. Backwash rate, $QB = 20$ gpm/ft^2
3. Downtime per backwash, $TB = 10$ min.
4. Filter bed depth, $D = 2$ ft.

The influent stream characteristics used in the analysis are given below:

Flow-rate, mgd	10
Solid organic carbon, mg/l	105
Solid nonbiodegradable carbon, mg/l	30
Solid organic nitrogen, mg/l	10
Solid organic phosphorous, mg/l	2
Solid fixed matter, mg/l	30
Solid 5-day BOD, mg/l	140
Volatile suspended solids, mg/l	224
Total suspended solids, mg/l	254
Dissolved organic carbon, mg/l	43
Dissolved nonbiodegradable carbon, mg/l	11
Dissolved nitrogen, mg/l	19
Dissolved phosphorous, mg/l	4
Dissolved fixed matter, mg/l	500
Alkalinity, mg/l	250
Dissolved 5-day BOD, mg/l	60
Ammonia nitrogen as N, mg/l	15
Nitrate as N, mg/l	0

Pertinent input design parameters for processes in the treatment system are listed with the tables of results.

Filtration Rate

The effect of the filtration rate on system cost and performance was determined using filtration rates from 2 to 10 gpm/ft^2. The results are listed in Table 3. Note that increasing the filtration rate in this range decreases the filter and total system costs appreciably. According to Eq. (4) increasing the filtration rate increases the backwash recycle rate. This increases the flowrate through the primary and secondary units. According to Table 3, the effect on system performance, in this case, is negligible.

Mixed Liquor Suspended Solids (MLSS)

The effect of the MLSS concentration on system cost and performance is listed in Table 4. In this case it appears that

Table 3. Effect of the Filtration Rate on Cost and Performance.

(GSS = 700 gpd/ft^2, MLSS = 2000 mg/l, E = 0.7)

			Effluent			
Filtration Rate, QF (gpm/ft^2)	Total Cost (¢/1000 gal)	Filter Cost (¢/1000 gal)	TSS (mg/l)	BOD (mg/l)	Total P (mg/l)	Total N (mg/l)
2	35.7	11.1	4.4	8.7	5.4	22.1
4	31.7	7.1	4.4	8.7	5.4	22.1
6	30.1	5.5	4.5	8.7	5.4	22.1
8	29.3	4.6	4.5	8.7	5.4	22.1
10	28.7	4.0	4.5	8.7	5.4	22.1

Table 4. Effect of MLSS on Cost and Performance

($QF = 4$ gpm/ft^2, $GSS = 800$ gpd/ft^2, $E = 0.5$)

			Effluent			
MLSS (mg/1)	Total Cost (¢/1000 gal)	Filter Cost (¢/1000 gal)	TSS (mg/1)	BOD (mg/1)	Total P (mg/1)	Total N (mg/1)
1000	32.63	7.09	10.3	8.9	5.4	22.3
1500	31.82	7.06	8.8	9.4	5.4	22.2
2000	31.40	7.04	7.9	9.7	5.4	22.2
3000	30.97	7.02	6.8	10.2	5.4	22.2
4000	30.95	7.00	6.1	9.7	5.4	21.9

the MLSS concentration has only a slight effect on the filtration process cost. However, increasing the MLSS concentration from 1000 to 4000 mg/l decreases the effluent TSS by approximately 40 percent, from 10.3 to 6.1 mg/l. A review of the design equations in the process subroutines suggests that this is primarily a result of increased secondary clarifier performance.

Secondary Clarifier Overflow Rate

An interesting trade-off exists between the secondary clarifier and the filters. As the clarifier overflow rate is increased the cost decreases and the effluent SS concentration increases. This increases the loading on the filters, which decreases the filtered water production per filter run, and increases the plan area requirement and cost. Table 5 shows the effect of increasing the overflow rate from 400 to 1200 gpd/ft^2 on cost and performance. Note that although the filtration process costs increase as expected, the overall system cost decreases with increasing overflow rate. The effluent TSS increases from 3.4 to 5.8 mg/l. For some undetermined reason the effluent BOD decreases slightly as the overflow rate is increased from 600 to 1200 gpd/ft^2. The overflow rate appears to have little effect on the total P and total N concentrations.

Table 5. Effect of the Secondary Clarifier Overflow Rate on Cost and Performance

(QF = 4 gpm/ft^2, MLSS = 2000 mg/1, E = 0.7)

			Effluent			
Overflow Rate, GSS (gpd/ft^2)	Total Cost (¢/1000 gal)	Filter Cost (¢/1000 gal)	TSS (mg/1)	BOD (mg/1)	Total P (mg/1)	Total N (mg/1)
400	32.48	7.04	3.0	8.8	5.4	21.9
600	31.82	7.08	4.1	9.0	5.4	22.1
800	31.61	7.11	4.7	8.5	5.4	22.1
1000	31.50	7.14	5.3	8.0	5.4	22.1
1200	31.43	7.16	5.8	7.7	5.4	22.1

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APPENDIX A
Program Listing for the FILT Subroutine

```
C          DUAL MEDIA FILTRATION                                        FIL00100
      SUBROUTINE FILT                                                   FIL00200
      INTEGER OS1,OS2                                                   FIL00300
      DIMENSION AK(6),BLOG(6)                                           FIL00400
      COMMON SMATX(20,30),TMATX(20,30),DMATX(20,20),OMATX(20,20),IP(20),FIL00500
     1INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(20,5),COSTO(20,5),ACOST(20,5)FIL00600
     2,ICOST(20,5),DHR,PCT,WPI,CLAND,DLAND                              FIL00700
      SMATX(2,OS1)=SMATX(2,IS1)                                         FIL00800
      DO 10 I=11,17                                                     FIL00900
   10 SMATX(I,OS1)=SMATX(I,IS1)                                         FIL01000
      FK=DMATX(6,N)                                                     FIL01100
      CO=SMATX(10,IS1)                                                  FIL01200
      D=DMATX(5,N)                                                      FIL01300
      QF=DMATX(3,N)                                                     FIL01400
      DELTH=DMATX(4,N)                                                  FIL01500
      AK(1)=DMATX(13,N)                                                 FIL01600
      AK(2)=DMATX(12,N)                                                 FIL01700
      AK(3)=DMATX(11,N)                                                 FIL01800
      AK(4)=DMATX(10,N)                                                 FIL01900
      AK(5)=DMATX(9,N)                                                  FIL02000
      AK(6)=DMATX(8,N)                                                  FIL02100
      E=DMATX(1,N)                                                      FIL02200
      DO 20 I=3,10                                                      FIL02300
   20 SMATX(I,OS1)=SMATX(I,IS1)*(1-E)                                   FIL02400
      F=DMATX(7,N)                                                      FIL02500
      TB=DMATX(2,N)                                                     FIL02600
      QB=DMATX(14,N)                                                    FIL02700
      ELF=DMATX(16,N)                                                   FIL02800
      Q=SMATX(2,IS1)                                                    FIL02900
      NF=6                                                              FIL03000
      CLOG=0.0                                                          FIL03100
      DO 50 I=1,6                                                       FIL03200
      IF (DELTH-AK(I)*D*QF) 40,30,30                                    FIL03300
   30 BLOG(I)=ALOG10(DELTH/(AK(I)*D*QF))                                FIL03400
      CLOG=CLOG+BLOG(I)                                                 FIL03500
      GO TO 50                                                          FIL03600
   40 DELTH=DELTH-AK(I)*D*QF/NF                                         FIL03700
   50 CONTINUE                                                          FIL03800
      WP=F*FK*D/(E*CO*NF)*CLOG                                          FIL03900
      WPN=1440.0/(WP/QF+TB)*(WP-TB*QB)                                  FIL04000
      A=Q/WPN*10.0**6.0                                                 FIL04100
      CCOST(N,1)=6378.1*A**0.66                                         FIL04200
      BMH=A/(0.1224+0.00058*A)                                          FIL04300
      BMC=451.33*A**0.68                                                FIL04400
      COMF=BMH*DHR/(3650.0*Q)                                           FIL04500
      COMV=BMC*WPI/(3650.0*Q)                                           FIL04600
      COSTO(N,1)=COMF+COMV                                              FIL04700
      SMATX(2,IS2)=QB*TB/(WP/QF+TB)*A*0.00144                           FIL04800
      DO 60 I=3,17                                                      FIL04900
   60 SMATX(I,IS2)=SMATX(I,OS1)                                         FIL05000
      SMATX(2,OS2)=QB*TB/(WP/QF+TB)*A*0.00144                           FIL05100
      DO 70 I=3,10                                                      FIL05200
   70 SMATX(I,OS2)=WP*SMATX(I,IS1)*E/(QB*TB)+SMATX(I,IS2)               FIL05300
      DO 80 I=11,17                                                     FIL05400
   80 SMATX(I,OS2)=SMATX(I,IS2)                                         FIL05500
      OMATX(1,N)=WP                                                     FIL05600
      OMATX(2,N)=A                                                      FIL05700
      OMATX(3,N)=WPN                                                    FIL05800
      OMATX(4,N)=E                                                      FIL05900
      RETURN                                                            FIL06000
      END                                                               FIL06100
```

APPENDIX B
Modifications to EXECMAIN

```
 410 IF (IFAIL) 760,760,360                                             EXE24600
 420 GO TO (430,440,450,460,470,480,490,500,510,520,530,540,550,560,570EXE24700
    1,580,590,600,610,620,630,640,650,660,665), IPROC
                                                                        EXE24900
 430 CALL PREL                                                          EXE25000
     GO TO 670                                                          EXE25100
 440 CALL PRSET                 modified                                EXE25200
     GO TO 670                    statement                             EXE25300
 450 CALL AERFS                                                         EXE25400
C                                                                       EXE25500
C                                                                       EXE25600
C            IF THE REQUIRED MLASS, BODS OR MLSS CAN NOT BE ATTAINED    EXE25700
C            IN THE AERFS SUBROUTINE, IAERF WILL BE RETURNED FROM       EXE25800
C            AERFS WITH A VALUE OF 1 (ONE) - THIS TRANSFER CONTROL      EXE25900
C            TO STATEMENT 760 WHICH WILL TERMINATE THE DESIGN CASE      EXE26000
C                                                                       EXE26100
     IF (IAERF) 670,670,760                                             EXE26200
 460 CALL MIX                                                           EXE26300
     GO TO 670                                                          EXE26400
 470 CALL SPLIT                                                         EXE26500
     GO TO 670                                                          EXE26600
 480 CALL DIG                                                           EXE26700
     GO TO 670                                                          EXE26800
 490 CALL VACF                                                          EXE26900
     GO TO 670                                                          EXE27000
 500 CALL THICK                                                         EXE27100
     GO TO 670                                                          EXE27200
 510 CALL ELUT                                                          EXE27300
     GO TO 670                                                          EXE27400
 520 CALL SBEDS                                                         EXE27500
     GO TO 670                                                          EXE27600
 530 CALL TRFS                                                          EXE27700
     GO TO 670                                                          EXE27800
 540 CALL CHLOR                                                         EXE27900
     GO TO 670                                                          EXE28000
 550 CALL TFLOT                                                         EXE28100
     GO TO 670                                                          EXE28200
 560 CALL MHINC                                                         EXE28300
     GO TO 670                                                          EXE28400
 570 CALL RWP                                                           EXE28500
     GO TO 670                                                          EXE28600
 580 CALL SHT                                                           EXE28700
     GO TO 670                                                          EXE28800
 590 CALL CENT                                                          EXE28900
     GO TO 670                                                          EXE29000
 600 CALL AEROB                                                         EXE29100
     GO TO 670                                                          EXE29200
 610 CALL POSTA                                                         EXE29300
     GO TO 670                                                          EXE29400
 620 CALL EQUAL                                                         EXE29500
     GO TO 670                                                          EXE29600
 630 CALL DIG2                                                          EXE29700
     GO TO 670                                                          EXE29800
 640 CALL LANDD                                                         EXE29900
     GO TO 670                                                          EXE30000
 650 CALL LIME              added statements                            EXE30100
     GO TO 670                                                          EXE30200
 660 CALL RBC
     GO TO 670
 665 CALL FILT                                                          EXE30300
C                                                                       EXE30400
C
```

APPENDIX C
Modifications to PRINT

```
C                                                                       PRT03000
C                                                                       PRT03100
C            OUTPUT FORMAT FOR PROCESS CHARACTERISTICS AND PARAMETERS   PRT03200
C                                                                       PRT03300
      WRITE (10,50)                                                     PRT03400
   50 FORMAT (1H1,////,44X,'PROCESS CHARACTERISTICS',//,58X,'CCOST = CAPPRT03500
     1ITAL COST, DOLLARS',/,58X,'COSTO = OPERATING + MAINTENANCE COST, CPRT03600
     2ENTS/1000 GAL.',/,58X,'ACOST = AMORTIZATION COST, CENTS/1000 GAL.'PRT03700
     3,/,58X,'TCOST = TOTAL TREATMENT COST, CENTS/1000 GAL.',//)        PRT03800
      DO 610 I=1,20                                                     PRT03900
      IF (IP(I)) 60,610,60                                              PRT04000
   60 KK=IP(I)                                                          PRT04100
      GO TO (70,90,110,610,610,140,160,180,200,220,240,270,300,320,350,3PRT04200
     170,390,410,440,480,510,530,560,580,602), KK
C                                                                       PRT04400
C                                                                       PRT04500
C                 PREL                                                  PRT04600
C                                                                       PRT04700
```

modified statement

```
C                                                                       PRT32700
C                                                                       PRT32800
C                 RBC                                                   PRT32900
C                                                                       PRT33000
  580 WRITE (10,590) I,(DMATX(J,I),J=1,9),(DMATX(J,I),J=1,10)           PRT33100
  590 FORMAT (1X,1HP,I2,2X,'ROTATING',11X,'BOD',4X,'XNSTG',5X,'DEGC',4X,PRT33200
     1'QPABI',4X,'QPANI',6X,'GSS',5X,'BODN',6X,'TSS',5X,'CPUT',/,6X,'BIOPRT33300
     2LOGICAL',5X,2F9.1,3F9.2,2F9.1,2F9.2,/,6X,'CONTACTOR-',/,6X,'FINAL PRT33400
     3SETTLER',5X,'QPAB',5X,'QPAN',4X,'APSTG',5X,'AREA',4X,'FNSTG',4X,'RPRT33500
     4NSTG',4X,'RATIO',5X,'PREM',5X,'QPAT',6X,'AFS',/,21X,2F9.2,2F9.0,2FPRT33600
     59.2,F9.3,F9.2,F9.3,F9.1,/)                                        PRT33700
      WRITE (10,600) (DMATX(J,I),J=11,17),CCOST(I,1),COSTO(I,1),ACOST(I,PRT33800
     11),TCOST(I,1),DMATX(18,I),CCOST(I,2),COSTO(I,2),ACOST(I,2),TCOST(IPRT33900
     2,2),DMATX(15,I)                                                   PRT34000
  600 FORMAT (24X,'PDSD',5X,'ORSS',5X,'NTRN',4X,'NSHFT',4X,'COSTM',4X,'CPRT34100
     1OSTE',4X,'COSTL',/,21X,F9.1,F9.3,2F9.1,3F9.0,//,68X,'CCOST',4X,'COPRT34200
     2STO',4X,'ACOST',4X,'TCOST',6X,'ECF',/,57X,'CONTACTOR',F9.0,3F9.3,FPRT34300
     39.2,//,57X,'FINAL',4X,F9.0,3F9.3,F9.2,/,57X,'SETTLER',//)         PRT34400
      GO TO 610
C
C
C                 FILT
C
  602 WRITE(10,604) I,DMATX(4,I),(DMATX(J,I),J=2,14),(DMATX(J,I),J=1,3)
  604 FORMAT(1X,1HP,I2,2X,'DUAL-',14X,'L',7X,'TH',7X,'QF',5X,'DELTH',8X,
     1'U',4X,'FR',9X,'F',9X,'AK(6)',3X,'AK(5)',4X,'AK(4)',/,6X,'MEDIA FI
     2LTER',3X,5F9.2,F9.0,4F9.2,//,24X,'AK(3)',3X,'AK(2)',5X,'AK(1)',5X,
     3'WB',6X,'HP',7X,'A',7X,'WPN',6X,/,21X,4F9.2,3F9.1,//)
      WRITE(10,606) CCOST(I,1),COSTO(I,1),ACOST(I,1),TCOST(I,1),DMATX(16
     1,I)
  606 FORMAT(68X,'CCOST',4X,'COSTO',4X,'ACOST',4X,'TCOST',6X,'ECF',/,66X
     1,F9.0,3F9.3,F9.2,//)
  610 CONTINUE                                                          PRT34500
C                                                                       PRT34600
C                                                                       PRT34700
C            OUTPUT FORMAT FOR COSTS OF MISCELLANEOUS FACILITIES        PRT34800
C                                                                       PRT34900
```

added statements

CASE VII WORKSHOP

MODIFICATIONS OF EXISTING DESIGN SUBROUTINES FOR PROCESS SIMULATION STUDIES

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ABSTRACT

The original process subroutines of the Executive Program were developed for use as a design tool for sizing and cost estimating new facilities. The programs can be used for process simulations by calculating a series of cases with different input values for flow rate, effluent concentrations and other major process variables. However, process simulation calculations for a fixed size processing unit can be facilitated by making minor changes in the subroutines. The size of the process units are given as data input and effluent characteristics are calculated as output.

PROCESS SIMULATION

Process simulation studies are widely used in the chemical and metallurgical industries:

a) to establish process variable effects
b) to establish pseudo optimum conditions
c) to provide a framework for process performance analysis

Process design and process simulationare closely related. Design calculations make use of available correlations to calculate residence time, chemical addition rates, and recycle rates to achieve a desired effluent. Formulation of operating strategies are another example where process simulation is a prerequisite. The objective is to define process variable control points to achieve a desired effluent quality or performance level; for example, in activated sludge treatment controllable process variables such as recycle rate, sludge draw-off and air supply rates must be specified as a function of raw sewage flow rates, incoming BOD and temperature.

Computerized process control can be considered as an ongoing process simulation in which actual performance is compared to the process simulation model results in order to evaluate the need for changing the set points of the controls.

It is obvious that process simulations are no better than the mathematical models correlations, and data that go into them. Mathematical models of fluid flow are well defined so that flow systems, e.g. pipe networks, sewer systems are susceptible to precise simulation. The physical separation processes such as sedimentation can also be modeled with good success provided the size, shape and density characteristics of the solid particles can be described. However, modelling biological processes are still in their infancy and the available process models are not as precise as one could wish for. Process simulation of activated sludge treatment has been only marginally successful. This is largely due to the fact that the process simulations are based on over simplified mathematical models which treat waste materials as a single constituent when it actually consists of many different constituents and treats the active biomass as though it were a single species of bacteria rather than a mixture of microorganisms. More sophisticated models are being developed that rectify some of these shortcomings. These newer models will incorporate variable microorganism and enzyme concentrations as well as variable waste composition and flow rate. The point is that they will be far too complicated for hand calculation and will have to be programmed for computer applications.

The Executive Digital Computer Program is a first generation process model. It was intended to be used for preliminary process design, e.g. to calculate equipment size (detention time) and investment-operating costs for a specified flow rate, raw waste characteristic and effluent characteristics. In this form it is a very useful tool for comparing alternate processing sequences and for comparing the cost effectiveness of alternatives. In its present form the program calculates the complete process flow and mass balances on each of the major constituents for any specified effluent characteristic. In order to apply the program to existing facilities where detention time is fixed and effluent characteristics are variable, the program needs to be modified. Size of equipment (detention time) is specified as input and effluent concentration is treated as the dependent variable calculated using the same process correlations. Two examples are described; the primary sedimentation subroutine is modified to allow calculating effluent concentration using a sedimentation tank of a fixed size and allowing the flow rate and/or the raw waste water characteristics to change. The second example illustrates a modification of the activated sludge subroutine to allow calculating effluent BOD_5 concentrations for different flow rates but using an aeration basin of fixed size.

PRIMARY SEDIMENTATION SUBROUTINE (PRSET)

The existing subroutine calculates the overflow rate and hence the tank surface area required to achieve a specified degree of solids capture. The revised subroutine specifies the size of the sedimentation tank as data input and calculates the fraction of solids removed. The revised subroutine therefore allows calculating solids removal for different raw sewage flow rates (variable Q) and for different raw sewage suspended solids concentrations. The subroutine for primary sedimentation relates solids removal to overflow rate using a modified form of the correlation from "ASCE Manual of Practice, #36, 1959".

$$FRPS = 0.82\ e^{-(GPS/2780)}$$

where FRPS = fraction of incoming suspended solids removed in the settler

GPS = overflow rate gal/day-ft^2

The overflow rate (GPS) determines the required surface area of tank for any given flow rate. The degree of thickening of the underflow is specified as input; URPS is the ratio of suspended solids in the incoming sewage. All suspended solids (organic carbon, nitrogen and phosphorus) are assumed to follow the same distribution. Input is required for FRPS, URPS, HPWK and ECF (excess capacity factor).

The revised program deletes the input value for FRPS and substitutes data input for the tank surface area (APS); the process variable correlations are rewritten in order to calculate the value of GPS from the given tank surface area and the design flow rate (A). This allows calculating FRPS and the concentration of solids in the overflow and sludge stream as in the original program. The pertinent Fortran program statements are listed in Table 1.

Table 2 lists the program changes and the required Input/Output changes. The proposed change in the second data card which specifies a value for KEEY allows using either the original design program or the modified program. If the original program is used (KEEY=0), a value for FRPS must be specified as input; if the modified program is used (KEEY=1), APS must be specified as input on the first data card of PRSET.

Use of the modified PRSET program is illustrated below using the common treatment scheme outlined in Table 3. The parameter variations and calculated effluent suspended solids concentrations are listed in Table 4 and shown graphically in Figures 1-2.

Using a fixed value of APS 93,7000 ft^2) and influent suspended solids concentration of 260 mg/l, the supernatant suspended solids concentration is shown to increase with flow rate (Figure 1). The advantage in using the computer program for this type of analysis is that it automatically material balances the whole plant, that is, it includes the effects of recycle of supernatant from downstream process units back to the primary clarifier.

ACTIVATED SLUDGE-FINAL SEDIMENTATION SUBROUTINE (AERFS)

The combined activated sludge-final sedimentation process subroutine is designed to calculate the aeration tank volume, reciruclation rate, surface area of the final sedimentation basin, and the air requirement for specified input values of raw waste flows, effluent BOD, mixed liquor suspended solids concentration, biochemical rate coefficient, temperature, oxygen transfer efficiency, minimum dissolved oxygen concentration in the aerator, and the overflow rate and thickening capacity of the final clarifier. The revised program specifies the volume of the aeration tank (VAER) and allows calculating either effluent BOD for a specified value of mixed liquor suspended solids (MLSS) or it calculates the required MLSS to achieve a desired effluent BOD.

Process performance is described by a simple first order growth rate equation which relates the six major process variables of the aerator.

TABLE 1

Modified Subroutine PRSET

```
C                                                                       PRS00100
C             PRIMARY SEDIMENTATION                                     PRS00200
C             PROCESS IDENTIFICATION NUMBER   2                         PRS00300
C                                                                       PRS00400
      SUBROUTINE PRSET                                                  PRS00500
C                                                                       PRS00600
C                                                                       PRS00700
C             COMMON INITIAL STATEMENTS                                 PRS00800
C                                                                       PRS00900
      INTEGER OS1,OS2                                                   PRS01000
      COMMON SMATX(20,30),TMATX(20,30),DMATX(20,20),OMATX(20,20),IP(20),PRS01100
     1INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(20,5),COSTO(20,5),ACOST(20,5)PRS01200
     2,TCOST(20,5),DHR,PCT,WPI,CLAND,DLAND,FLOW(25),POW(25),TKWHD(25)   PRS01300
      COMMON/KEEY/KEEY                                                      *
C                                                                       PRS01400
C                                                                       PRS01500
C             ASSIGNMENT OF DESIGN VALUES TO PROCESS PARAMETERS         PRS01600
C                                                                       PRS01700
      HPWK=DMATX(3,N)                                                   PRS01800
      IF(KEEY.EQ.0) GO TO 40                                                *
      APS=DMATX(4,N)                                                        *
      GPS=SMATX(2,IS1)*1000./APS                                            *
      FRPS=EXP((-GPS-551.7)/2780.)                                          *
      DMATX(1,N)=FRPS                                                       *
C                                                                       PRS01900
C                                                                       PRS02000
C             PROCESS RELATIONSHIPS REQD. TO CALC. EFFLUENT STREAM      PRS02100
C             CHARACTERISTICS                                           PRS02200
C                                                                       PRS02300
   40 SMATX(2,OS2)=DMATX(1,N)*SMATX(2,IS1)/DMATX(2,N)                      **
      SMATX(2,OS1)=SMATX(2,IS1)-SMATX(2,OS2)                            PRS02500
      TEMP1=(1.-DMATX(1,N))*SMATX(2,IS1)/SMATX(2,OS1)                   PRS02600
      TEMP2=DMATX(1,N)*SMATX(2,IS1)/SMATX(2,OS2)                        PRS02700
C                                                                       PRS02800
C                                                                       PRS02900
C             EFFLUENT STREAM CALCULATIONS                              PRS03000
C                                                                       PRS03100
      DO 10 I=3,10                                                      PRS03200
      SMATX(I,OS1)=TEMP1*SMATX(I,IS1)                                   PRS03300
   10 SMATX(I,OS2)=TEMP2*SMATX(I,IS1)                                   PRS03400
      DO 20 I=11,20                                                     PRS03500
      SMATX(I,OS2)=SMATX(I,IS1)                                         PRS03600
   20 SMATX(I,OS1)=SMATX(I,OS2)                                         PRS03700
C                                                                       PRS03800
C                                                                       PRS03900
C             CALC. OF OUTPUT SIZES AND QUANTITIES                      PRS04000
C                                                                       PRS04100
      PGPH=SMATX(2,OS2)*116666.7/HPWK*DMATX(15,N)                       PRS04200
      IF(KEEY.EQ.1) GO TO 50                                                *
      GPS=-2780.*ALOG(DMATX(1,N))-551.7                                 PRS04300
      APS=SMATX(2,IS1)*1000./GPS                                           **
   50 APS=APS*DMATX(16,N)                                                  **
C                                                                       PRS04500
C                                                                       PRS04600
C             CALC. OF CAPITAL COSTS FOR PRIMARY SETTLER BASIN BASED    PRS04700
```

Note: The subroutine was modified by adding 7 statements; the additional statements are identified by asterisks. Changes in Input/Output are listed in Table 2.

TABLE 2

Modification of PRSET Subroutine Program

Computer program changes

(a) Added statements (*):

Statements between PRS01800 and PRS01900

Statements between PRS04200 and PRS04300

(b) Replaced or modified statements (**)

Statements between PRS02300 and PRS02500

Statements between PRS04300 and PRS04500

Input/output change

(a) Second data card: Between column 1-2, add KEEY=I2

KEEY=0: Original program

KEEY=1: Modified program

(b) Add DMATX(4,N) as required input value to the first data card of PRSET.

(c) Add common statement at beginning of the PRSET subroutine

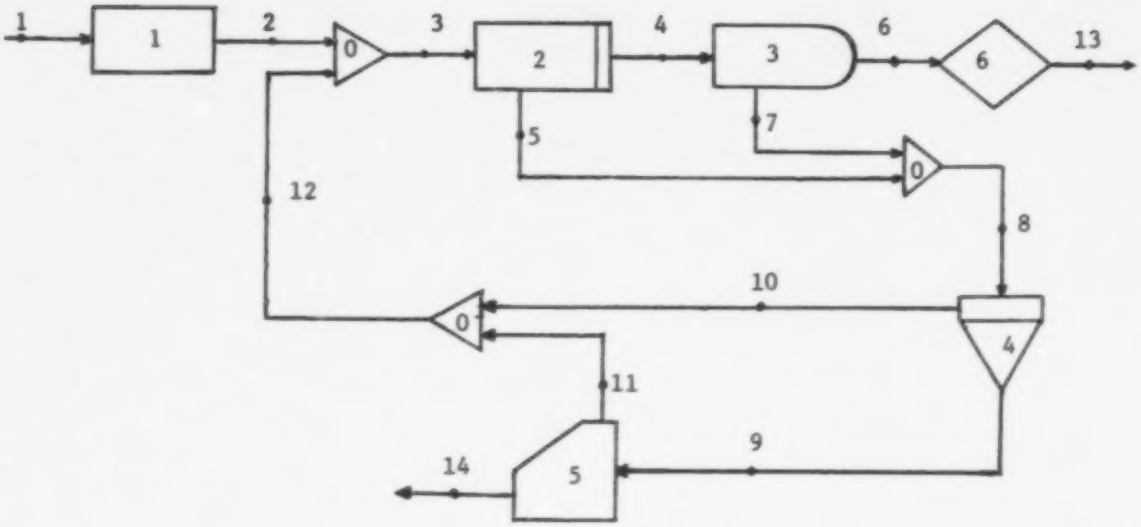
```
COMMON/KEEY/KEEY
```

(d) Add common statement at beginning of executive program:

```
COMMON/KEEY/KEEY
```

Table 3

Common Treatment Flow Diagram


1
1
2
0
3
2
4
3
6
6
13
5
7
0
12
8
10
0
4
11
9
14
5

K	N	IPROC	PROCESS	IS1	IS2	OS1	OS2
0	1	1	PREL	1	0	2	0
1	0	4	MIX	2	12	3	0
0	2	2	PRSET	3	0	4	5
0	3	3	AERFS	4	0	6	7
1	0	4	MIX	5	7	8	0
0	4	8	THICK	8	0	9	10
0	5	7	VACF	9	0	14	11
1	0	4	MIX	10	11	12	0
0	6	12	CHLOR	6	0	13	0

Table 4

PRSET - Parameter Variations and Output Results

flow rate Q (mgd)	influent SS (mg/ℓ)	effluent SS (mg/ℓ)
0.5	260	60
1.0	260	70
2.5	260	97
5.0	260	135
7.5	260	164
10.0	260	186
15.0	260	217
5	26	17
5	78	44
5	130	70
5	260	135
5	390	200
5	520	266
5	780	397
5	1300	658
10	1300	904

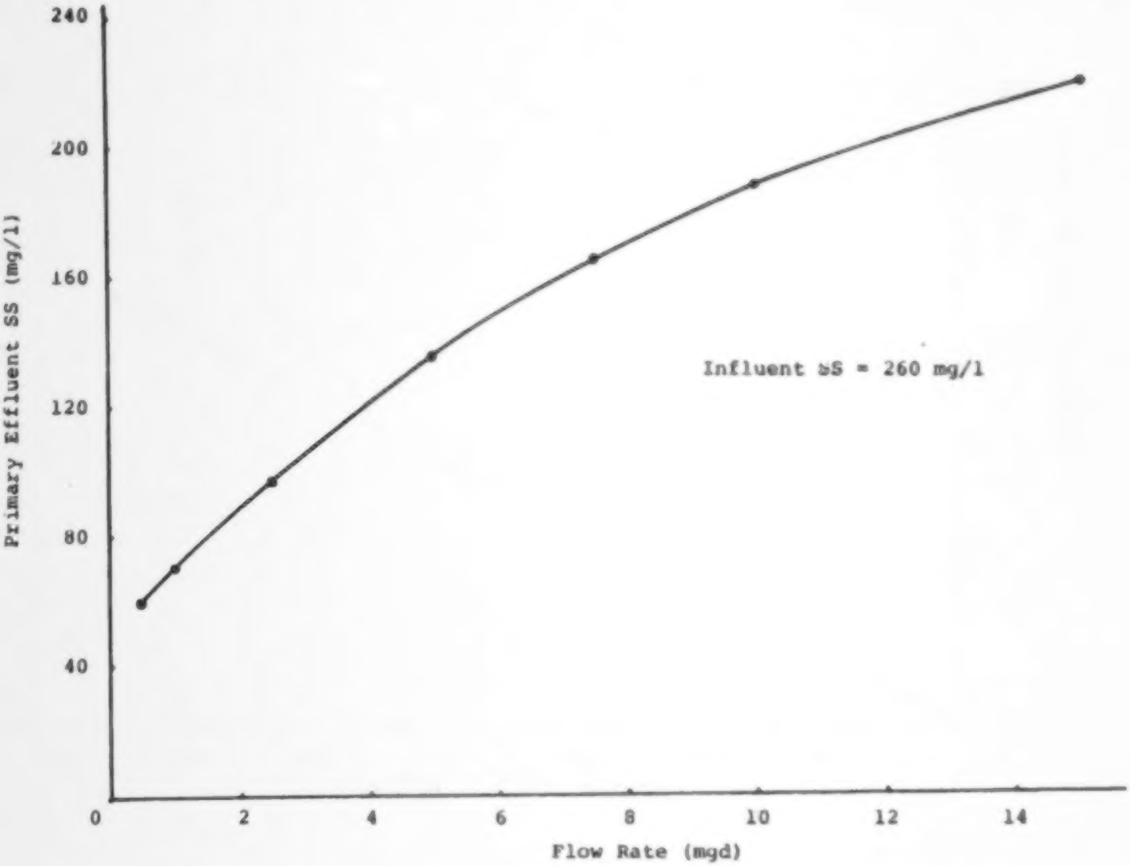


Fig. 1
Primary Effluent SS for Varying Flow Rate

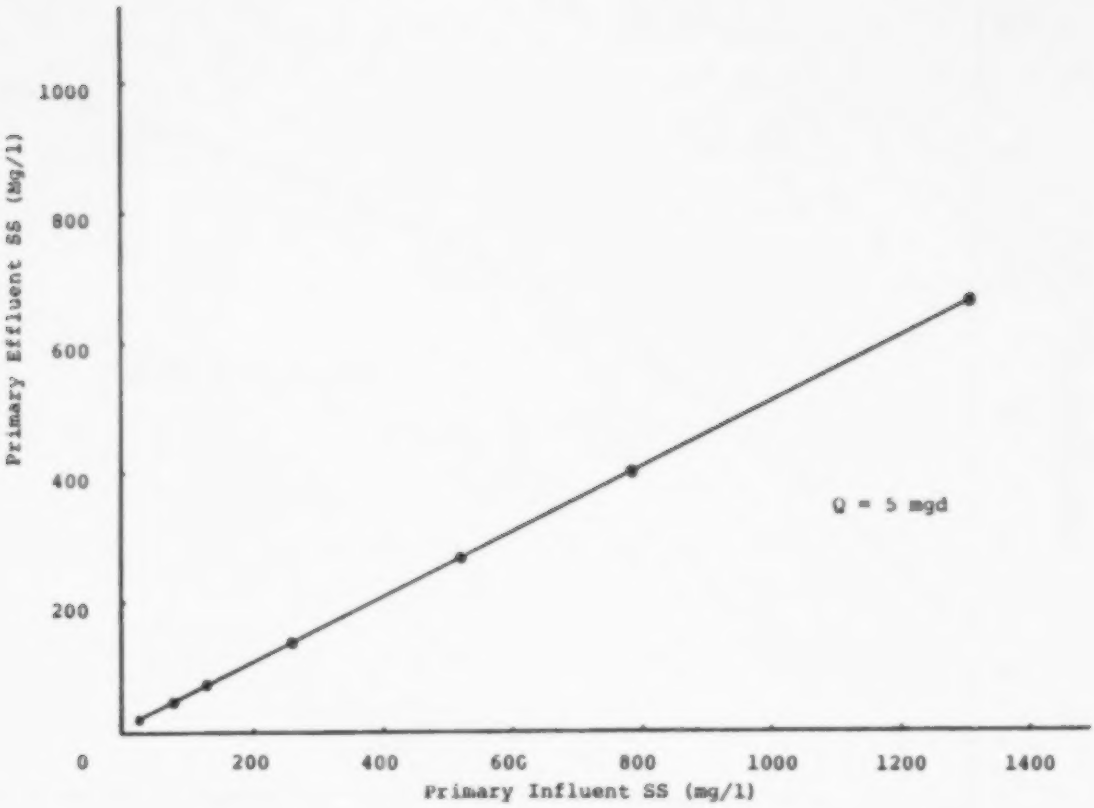


Fig. 2
Primary Effluent SS for Varying Primary Influent SS

$$A(BOD_{in}-BOD_{out}) = (BOD_{out})(CAER)\ (MLSS)\ (VAER)$$

where: Q = flow rate

BOD_{in} = inlet BOD_5

BOD_{out} = outlet BOD_5 which is equivalent to the BOD_5 in the aerator for a well mixed reactor

CAER = rate coefficient corrected for temperature

MLSS = mixed liquor suspended solids concentration

VAER = aeration tank volume.

By specifying any combination of 5 variables, the equation can be solved for the 6th unspecified variable.

The existing program specifies the first five variables as input and calculates VAER. The modified program uses the same equation; it has two options that allow calculating BOD_{out} or MLSS concentration. The pertinent Fortran program sections of the AERFS subroutine are listed in Table 5; the program changes are listed in Table 6 along with the changes in Input/Output. Program changes are keyed in the second data card by specifying a value for KEY. The original design program is used for KEY = 0. By setting KEY = 1, the program reads in a value for VAER and calculates the effluent BOD concentration. For KEY = 2, the program reads in VAER and BOD_{out} and calculates the required MLSS concentration in the aerator.

Use of the modified AERFS program is illustrated using the common treatment scheme outlined in Table 3. The parameter variations and calculated values are listed in Table 7 and illustrated graphically in Figures 3-5.

ASSIGNED PROBLEM

Participants may choose to use the prepared program modifications to carry out a short process variable study or to modify one of the other subroutines as an exercise.

a) Process variable studies

Using the common data input from previous problems modify the appropriate data input cards and use the revised program to calculate effluent characteristics for a series of flow rates ranging from 25 percent to 300 percent of the base case.

b) Modification of other subroutines, e.g., thickener or trickling filters-final sedimentation.

Table 5

Modified Subroutine AERFS

```
C                                                                       AEF00100
C             ACTIVATED SLUDGE - FINAL SETTLER                          AEF00200
C             PROCESS IDENTIFICATION NUMBER   3                         AEF00300
C                                                                       AEF00400
      SUBROUTINE AERFS                                                  AEF00500
C                                                                       AEF00600
C                                                                       AEF00700
C             COMMON INITIAL STATEMENTS                                 AEF00800
C                                                                       AEF00900
      INTEGER OS1,OS2                                                   AEF01000
      COMMON SMATX(20,30),TMATX(20,30),DMATX(20,20),OMATX(20,20),IP(20),AEF01100
     1INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(20,5),COSTO(20,5),ACOST(20,5)AEF01200
     2,TCOST(20,5),DHR,PCT,WPI,CLAND,DLAND,FLOW(25),POW(25),TKWHD(25)   AEF01300
      COMMON/KEY/KEY                                                       *
C                                                                       AEF01400
C                                                                       AEF01500
C             PROCESS RELATIONSHIPS REQD. TO CALC. EFFLUENT STREAM      AEF01600
C             CHARACTERISTICS                                           AEF01700
C                                                                       AEF01800
      HEAD=DMATX(9,N)                                                   AEF01900
      BOD2=SMATX(8,IS1)+SMATX(17,IS1)                                   AEF02000
      DBOD2=SMATX(17,IS1)                                               AEF02100
      CEDR=.18*1.047**(DMATX(3,N)-28.)                                  AEF02200
      CAER=DMATX(4,N)*1.047**(DMATX(3,N)-20.)                           AEF02300
      IF(KEY.EQ.0) GO TO 1000                                              *
      VAER=DMATX(11,N)                                                     *
      TA=VAER/SMATX(2,IS1)                                                 *
      IF(KEY.EQ.1) GO TO 1000                                              *
      SA=(BOD2-DMATX(1,N))/(DMATX(1,N)*CAER*TA*24.)                        *
      XMLSS=SA*1000.                                                       *
      DMATX(2,N)=XMLSS                                                     *
      GO TO 3000                                                           *
 1000 SA=DMATX(2,N)/1000.                                                  **
      IF(KEY.EQ.0) GO TO 2000                                              *
      BOD=BOD2/(1.+TA*CAER*SA*24.)                                         *
      DMATX(1,N)=BOD                                                       *
      GO TO 3000                                                           *
 2000 TA=(BOD2-DMATX(1,N))/(DMATX(1,N)*CAER*SA*24.)                        **
      VAER=SMATX(2,IS1)*TA                                              AEF02600
 3000 XRSS=556.1*DMATX(8,N)**.4942/DMATX(2,N)**1.8165/(TA*24.)**.4386      **
      ALD=DMATX(10,N)*.87*SMATX(14,IS1)                                 AEF02800
      IF (ALD) 10,20,10                                                 AEF02900
   10 PALS=1.305*SMATX(14,IS1)+3.*ALD                                   AEF03000
      GO TO 30                                                          AEF03100
   20 PALS=0.                                                           AEF03200
   30 ASMAX=DMATX(1,N)/XRSS/.685                                        AEF03300
      ASMIN=0.                                                          AEF03400
      NAER=0                                                            AEF03500
      IF (ASMAX-DMATX(2,N)) 50,50,40                                    AEF03600
   40 ASMAX=DMATX(2,N)                                                  AEF03700
   50 XMLAS=(ASMAX+ASMIN)/2.                                            AEF03800
      FOOD=SMATX(8,IS1)+DBOD2                                           AEF03900
      FMAX=FOOD                                                         AEF04000
      N1=1                                                              AEF04100
      GO TO 110                                                         AEF04200
```

Note: The program was modified by adding 13 statements; the additions are identified by an asterisk. The changes in input/output are described in Table 6.

Table 6

Modification of AERFS Subroutine Program

<u>Program changes</u>

1. To find BOD from given VAER

```
     VAER=DMATX(11,N)
     TA=VAER/SMATX(2,IS1)
      ------}
            }- skip 4 statements
      ------}
1000 SA=DMATX(2,N)/1000.
     IF(KEY.EQ.0) GO TO 2000
     BOD=BOD2/(1.+TA*CAER*SA*24.)
     DMATX(1,N)=BOD
     GO TO 3000
```

2. To find MLSS from given VAER and BOD

```
     VAER=DMATX(11,N)
     TA=VAER/SMATX(2,IS1)
     IF(KEY.EQ.1) GO TO 1000
     SA=(BOD2-DMATX(1,N))/(DMATX(1,N)*CAER*TA*24.)
     XMLSS=SA*1000.
     DMATX(2,N)=XMLSS
     GO TO 3000
```

3. Input/Output Change

a) 2nd data card: between column 3-4, add KEY=I2
K=0: Original program
K=1: Find BOD from given VAER
K=2: Find MLSS from given VAER and BOD

b) Input VAER=DMATX(11,N) on the second data card of AERFS. Calculations for BOD and MLSS are not affected by the XMLSS=DMATX(2,N) as required in the original program.

c) Add common statement at beginning of AERFS subroutine
COMMON/KEY/KEY

d) Add common statement at beginning of executive program
COMMON/KEY/KEY

Table 7

AERFS-Parameter Variations and Output Results

Flow Rate Q(mg/ℓ)	MLSS (mg/ℓ)	BOD (mg/ℓ)
0.5	2000	2.3
1.0	2000	4.5
1.5	2000	6.6
2.0	2000	8.7
3.0	2000	12.7
4.0	2000	16.5
5.0	2000	20.1
6.0	2000	23.6
7.5	2000	28.3
10.0	2000	35.6
15.0	2000	47.8
5.0	7357	6
5.0	4306	10
5.0	2015	20
5.0	849	40
5.0	455	60
5.0	400	64.5
5.0	600	50.8
5.0	1000	35.5
5.0	2000	20.1
5.0	4000	10.7
5.0	6000	7.3

Calculated values are enclosed by brackets.

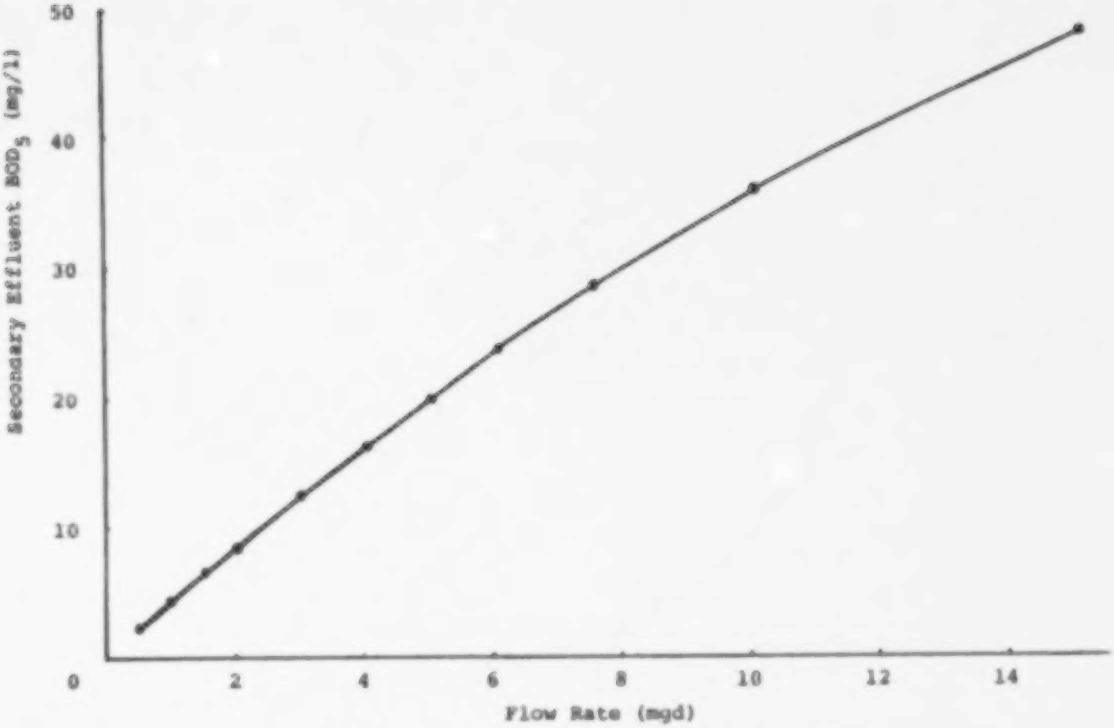


Fig. 3
Secondary Effluent BOD_5 for Varying Flow Rate (mg/l)

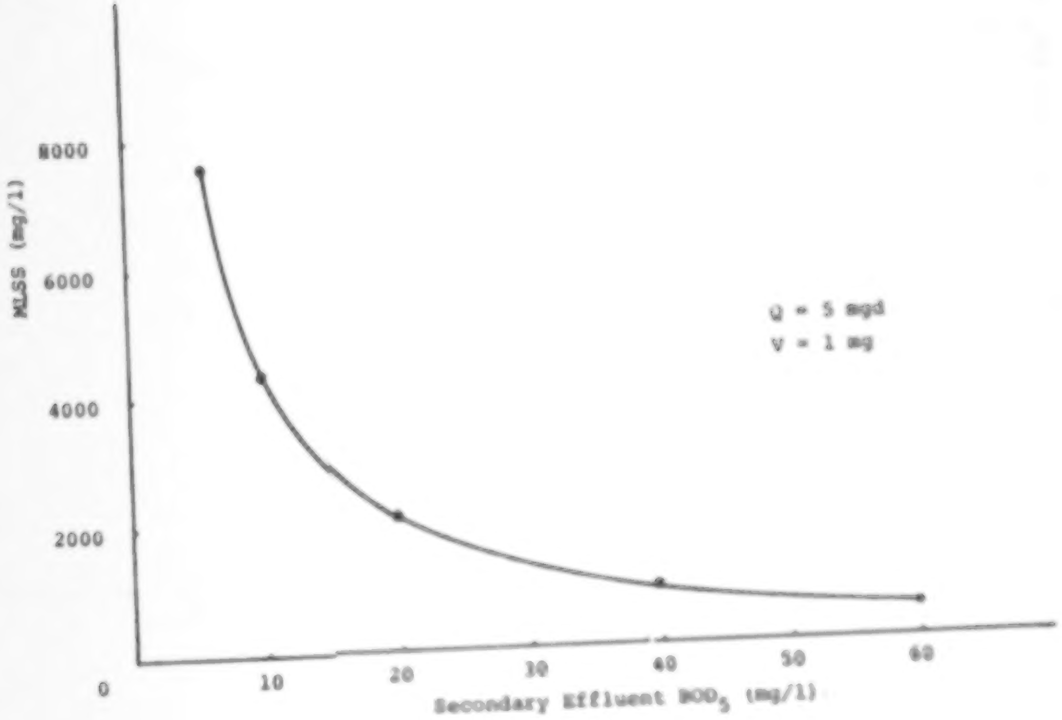


Fig. 4

MLSS For Varying Secondary Effluent SS (mg/l)

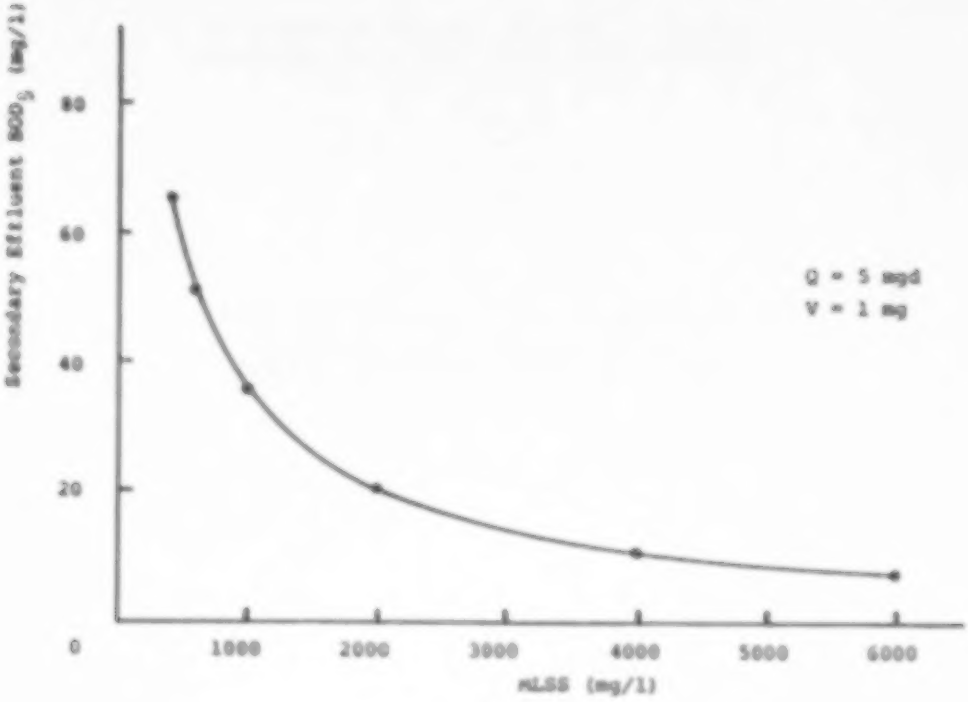


Fig. 5
Secondary Effluent BOD_5 For Varying MLSS (mg/l)

CASE VIII WORKSHOP

USE OF A STREAM IMPACT PROGRAM IN CONJUNCTION WITH THE EXEC PROGRAM

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ABSTRACT

A simple subroutine is described which will determine the dissolved oxygen concentration in a stream receiving waste from a treatment plant analyzed by the Exec program. The subroutine can be attached to, or incorporated into the Exec program to determine the downstream effect of wastewater treatment plant configurations. An example is given and suggestions are made for extensions and refinements of the subroutine.

INTRODUCTION

Planners and designers often require knowledge of the effects of a waste treatment plant downstream of the waste discharge, as well as the effluent quality itself. The Executive Program for Preliminary Design of Wastewater Treatment Systems provides characteristics of the effluent, but currently it is not capable of predicting downstream water quality as a function of treatment process parameters. However, several programs exist which can predict downstream water quality given the characteristics of the waste discharge. (Norton et al., 1974; Hydrocomp International, Incorporated, 1976).

This paper will briefly describe the basic theory behind receiving stream models in general, and also details on how to augment the Exec program with a simple receiving stream model. The resulting combination will not only allow the prediction of effluent water quality but also resulting downstream characteristics. This will permit comparison of the predicted pollutant concentration with surface water quality standards.

The receiving stream model requires input from the last treatment process in the system and external input describing the water quality upstream, and stream characteristics downstream of the treatment plant effluent.

The stream subroutine will model the dissolved oxygen concentration in the receiving stream. Dissolved oxygen is only one parameter of water quality, however, it is the most widely used indicator because:

(1) the mathematical relationship between DO and BOD is well understood.

(2) the effect on DO of other oxygen demanding matter can be predicted with reasonable accuracy, and

(3) DO itself affects the quality of a stream.

It should be noted that the DO concentration is not recorded in the stream matrix (SMATX) within the Exec program. In addition, not all processes use dissolved oxygen as a design parameter. Therefore, care must be taken in selecting process configurations that allow a reasonable estimate of the plant effluent dissolved oxygen concentration. If this cannot be accomplished, a reasonable value can be assumed and input as a subroutine modification.

The process symbol shown in Figure 1 will be used to represent the receiving stream subroutine.

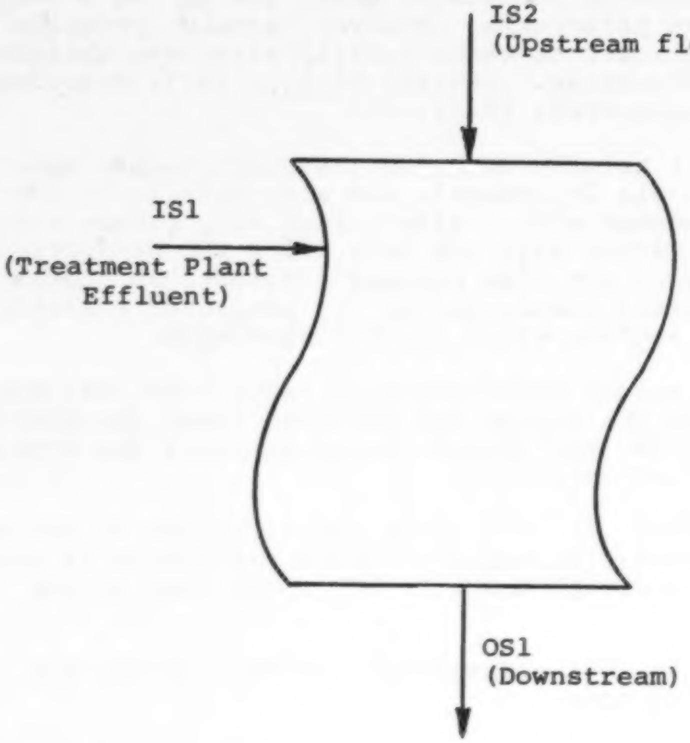

IS2
(Upstream flow)
IS1
(Treatment Plant Effluent)
OS1
(Downstream)

Figure 1. Process symbol for subroutine STREAM

RECEIVING STREAM MODEL

The subroutine developed for this case study is a simplified dissolved oxygen sag curve. The basic calculations are similar to many existing programs for calculating the DO concentration of a stream.

Basic Theory

The determination of the DO concentration is based on the assumption of a first order decay rate for BOD and a rate of change of dissolved oxygen proportional to the DO deficit. The resulting equation, originally developed by Streeter and Phelps (1925), is shown below:

$$D_t = \frac{k_1 L_o}{k_2 - k_1} (e^{-k_1 t} - e^{-k_2 t}) + D_o d^{-k_2 t} \qquad (1)$$

where:

D_t = the dissolved oxygen deficit at time t, mg/l,

k_1 = deoxygenation coefficient, days^{-1},

k_2 = reaeration coefficient, days^{-1},

L_o = initial BOD, mg/l, and

D_o = initial dissolved oxygen deficit at time O, mg/l.

The reaeration coefficient, k_2, is calculated knowing certain characteristics of the receiving stream (O'Conner and Dobbins, 1956):

$$k_2 = \frac{(D_m V)^{1/2}}{H^{3/2}} \qquad (2)$$

where:

D_m = molecular diffusivity of oxygen in water at 20°C, ft^2/day,

V = stream velocity, ft/day, and

H = stream depth, ft.

The saturation concentration of oxygen is calculated using:

$$C_s = 14.62 = 0.3898T + 0.00696T^2 = 0.00005897T^3 \qquad (3)$$

where:

T = temperature.

Using equation (1) the DO deficit, and therefore the DO concentration can be predicted as a function of distance in the downstream direction. A curve representing equation (1) is shown in Figure 2.

The minimum DO concentration occurs at time t_c. This critical time can be calculated by:

$$t_c = \frac{1}{k_2 - k_1} \ln \left[\frac{k_2}{k_1} \left(1 - \frac{(k_2 - k_1)D_o}{k_1 L_o}\right) \right] \qquad (4)$$

By substituting the value of t_c into equation (1), the maximum deficit (minimum concentration) can be determined. Likewise, knowing the travel time for a certain stream reach, we can also calculate the DO concentration at the end of the reach. Often the end of the stream reach comes before the critical time, making the concentration at the end of the reach the minimum concentration.

Equation (1) is valid for a stream reach with essentially constant characteristics. If the stream values change with distance downstream, then another calculation must be made. Typical changes include changes in the river cross-sectional area, changes in the value of the deoxygenation coefficient, k_1, and the inflow of a tributary or sewage treatment plant, which will change both the flow and water quality.

To handle such changes a new reach is defined and equation (1) is used to calculate new values for the second reach. Initial conditions for the second reach now correspond to a mixture of the end conditions for reach one and the tributary inflow (if a tributary exists). To determine the initial BOD, L_o, for the second reach, it is also necessary to calculate the BOD at the end of reach one. This is done using a simple first order decay equation:

$$L_t = L_o e^{-k_1 t} \qquad (5)$$

where:

L_t = BOD at time t.

A mass balance is calculated to determine the initial conditions for reach two given characteristics of both the upstream reach and influent tributary. Initial conditions include temperature, DO, BOD, and flow.

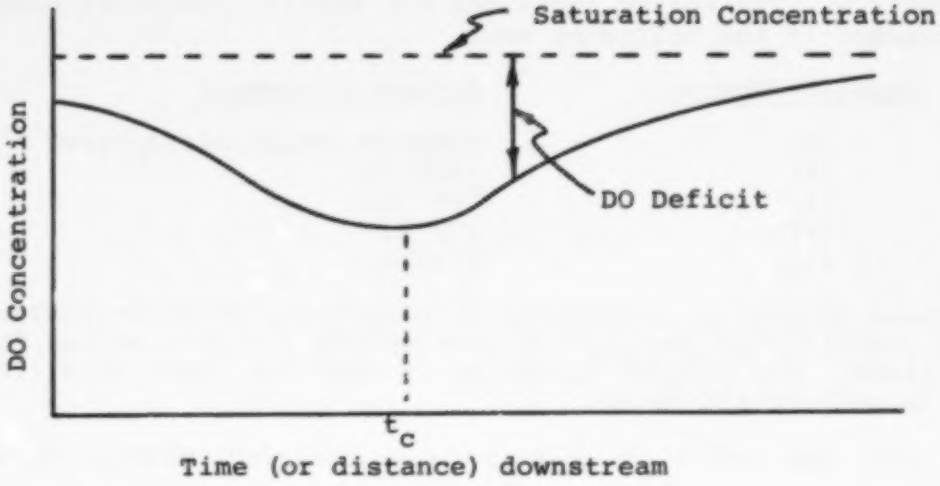


Figure 2. Typical dissolved oxygen concentration profile

Similar calculations can be made as we move downstream for any number of subsequent reaches. Figure 3 shows a typical curve for five reaches.

Subroutine STREAM

The previous theory has been incorporated into a simple computer program to illustrate one way of augmenting the Exec program with a stream impact model. Other possibilities and refinements will be discussed in a later section.

The Fortran listing for subroutine STREAM is shown in Appendix A. The theory equations and Fortran statement numbers correspond in the following way:

Equation Number	Fortran Statement
(1)	STRO8700,08800,09200,09300
(2)	STRO7200
(3)	STRO7800
(4)	STRO8600
(5)	STRO9400

The mass balance is calculated in statements STRO6100-06400. Each iteration of the problem corresponds to calculations for one reach. The program is set up to read one input card (in 315 format) to determine:

(1) the number of reaches to be analyzed, NREACH,[no units]

(2) the flow stream number corresponding to the effluent of the sewage treatment plant, ISTREM, [no units] and

(3) the last process in the treatment plant listing the effluent DO concentration, JPROC [no units]

The next input card (in 4F10.2 format) lists the river characteristics just upstream of the treatment plant discharge. They include:

(1) dissolved oxygen, DOUP, [mg/l]
(2) BOD, BODUP, [mg/l]
(3) flow, QUP, [ft^3/sec]
(4) temperature, TEMPUP [^{o}C]

The remaining data cards correspond to each reach of the receiving stream. The subroutine is set up so that each reach has a tributary at its head. If, in fact, no tributary exists, a tributary flow of zero is input. Each input card (in 8F10.2 format) will have:

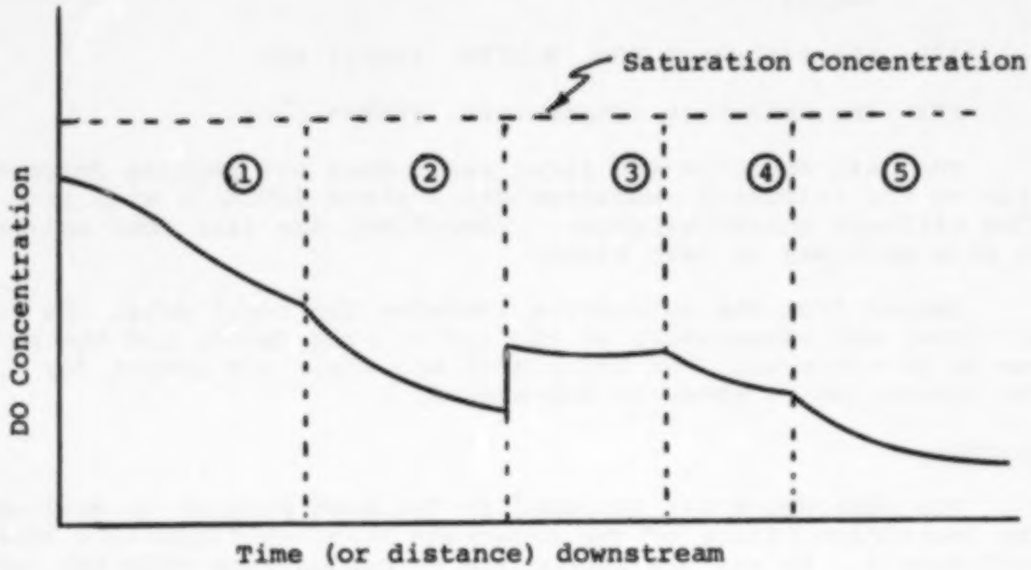


Figure 3. Dissolved oxygen concentration profile for a five reach stream

(1) the length of the reach, RLNGTH, [miles]

(2) the depth of the reach, DEPTH, [feet]

(3) the deoxygenation coefficient at 20^{o}C, XK1, [days^{-1}]

(4) the cross-sectional area of the reach, XAREA, [ft^{2}]

(5) the tributary flow, QTRIB, [ft^{3}/sec]

(6) the tributary dissolved oxygen concentration, DOTRIB, [mg/l]

(7) the tributary BOD, BODTRB, [mg/l] and

(8) the tributary temperature, TEMTRB [^{o}C].

The data card for the first reach does not require information on the tributary characteristics since EXECMAIN will provice effluent characteristics. Therefore, the last four entries on this card may be left blank.

Output from the subroutine includes the input data, the BOD, DO, flow, and temperature at the end of each reach, and the minimum DO in the reach. An example of the input and output for the subroutine is shown in Appendix B.

Example

The subroutine was appended to the Exec program to analyze the downstream effect of the treatment plant configuration shown in Figure 4. To use the subroutine in conjunction with the Exec program, one Fortran statement must be added to EXECMAIN. The statement:

```
CALL STREAM
```

must be added immediately after the CALL PRINT statement at the end of EXECMAIN.

To illustrate the effect of process variations, the effluent DO design parameters DMATX(4,6) for the post aeration process were varied to determine the effect on the stream. The results are shown in Table 1.

EXTENSIONS AND REFINEMENTS

Several refinements and extensions can, and should, be made before the subroutine can be applied effectively to a real world problem.

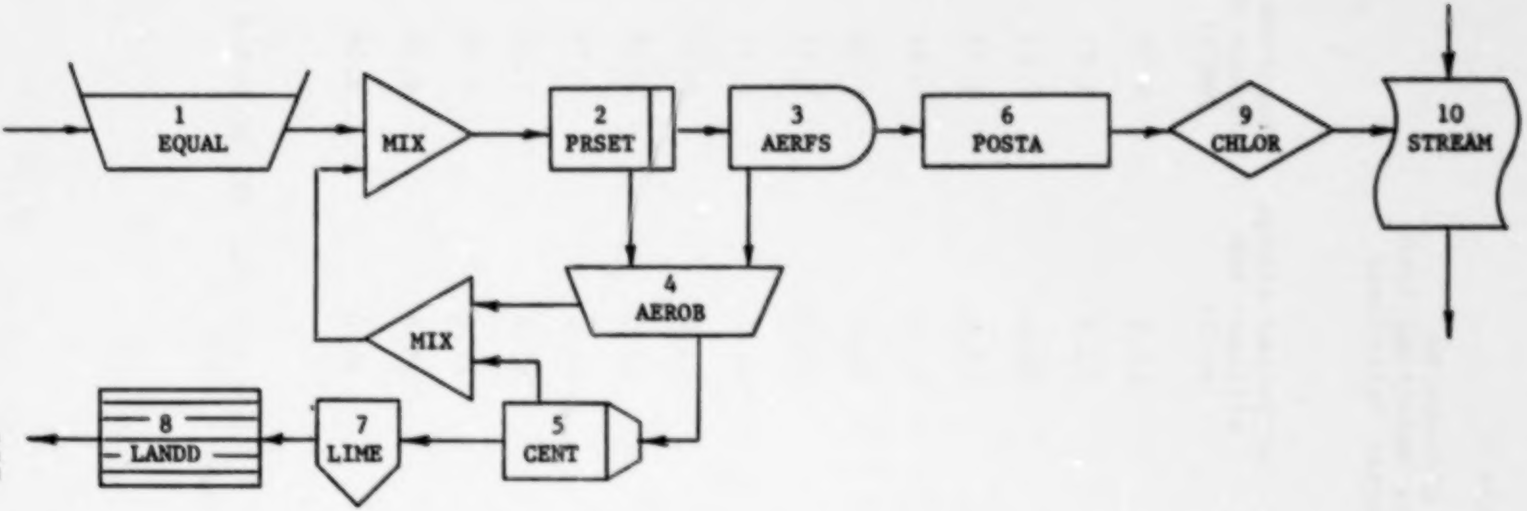

1
EQUAL
MIX
2
PRSET
3
AERFS
6
POSTA
9
CHLOR
10
STREAM
4
AEROB
MIX
5
CENT
7
LIME
8
LANDD

Figure 4 Process Configuration Used in Conjunction with STREAM Subroutine

Table 1

Instream Minimum DO Concentrations Resulting from Design Parameter Variations

Run No.	Plant Flow (MGD)	Post Aeration Effluent DO (mg/l)	Activated Sludge Effluent BOD (mg/l)	Instream Minimum DO (mg/l)
1	10	2.0	13.0	6.59
2	10	3.0	13.0	6.61
3	10	4.0	13.0	6.63
4	10	5.0	13.0	6.63
5	10	6.0	13.0	6.64
6	50	2.0	13.0	6.06
7	50	3.0	13.0	6.11
8	50	4.0	13.0	6.17
9	50	5.0	13.0	6.23
10	50	6.0	13.0	6.28
11	100	2.0	10.0	5.74
12	100	2.0	15.0	5.35
13	100	2.0	20.0	4.96
14	100	2.0	25.0	4.55
15	100	2.0	30.0	4.16

Note: Upstream characteristics (1) Q = 500 cfs, (2) DO = 9.0 mg/l, (3) BOD = 3.0 mg/l, (4) Temp = 15°C

Improved DO Equation

Equation (1) includes only two effects on the DO concentration. These are the BOD and the reaeration capability of the stream. Several other factors also effect the DO concentration and can be incorporated into the DO sag equation. These include:

(1) oxygen demand by benthic organisms,

(2) continuous input from overland flow or groundwater,

(3) reaeration due to photosynthesis, and

(4) scour of bottom deposits.

These effects are further discussed by Nemerow (1974) and Thomann (1972).

Other Parameters

As mentioned earlier, dissolved oxygen is only one measure of stream quality. The concentration of other pollutants can be as important in determining the quality of a stream and compliance with water quality standards. The stream subroutine could be expanded to calculate the concentrations of both conservative and non-conservative pollutants at various points downstream (Thomann, 1972).

Internalizing Subroutine STREAM

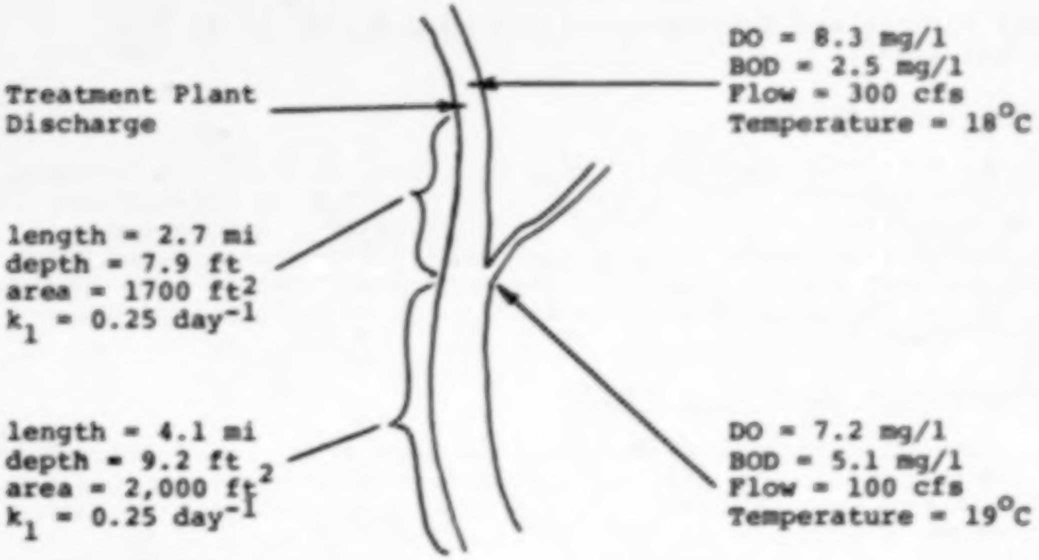
The subroutine described in this case study was developed to be independent of the Exec program and involve minimal modifications to the Exec program. It was also developed in this manner to provide a contrast to the approach taken in Case VI by Letterman. In his presentation, an additional subroutine was added to the Exec program as another process in the treatment plant. Input was accomplished using the existing DMATX and output was included in the PRINT subroutine. In this manner the subroutine was included in the iterations of the Exec program and sizing of the process was accomplished to meet prespecified design criteria.

The STREAM subroutine could also be included in such a way. This approach would allow the iterative process to use the DO concentration in the stream as a determining factor in the ultimate size of the treatment process. In conjunction with this approach, it is possible to include instream aeration in the STREAM subroutine. Work is in progress (Tabatabaie, 1977) to include a stream/instream aeration subroutine as a "process" in the wastewater treatment plant. Obviously such an analysis will depend heavily on streamflow characteristics, especially during low flow months. It is interesting to note, however, that during such periods even advanced waste treatment may not provide sufficient removal to maintain the surface water quality standards (Whipple et al., 1970).

ASSIGNED PROBLEM

As an assigned problem the short course participants may choose to pursue one of the following three exercises:

(1) Using the same process described in the write-up, evaluate the effect on a stream with the following characteristics:


Treatment Plant Discharge
DO = 8.3 mg/l
BOD = 2.5 mg/l
Flow = 300 cfs
Temperature = 18°C
length = 2.7 mi
depth = 7.9 ft
area = 1700 ft^2
k_1 = 0.25 day^{-1}
length = 4.1 mi
depth = 9.2 ft
area = 2,000 ft^2
k_1 = 0.25 day^{-1}
DO = 7.2 mg/l
BOD = 5.1 mg/l
Flow = 100 cfs
Temperature = 19°C

(2) Using the same receiving stream, evaluate the effect of a different process configuration, or

(3) Add statements to the subroutine to determine the concentration of dissolved fixed matter (DFM) at the end of each stream reach.

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Nemerow, N. L. 1974. Scientific Stream Pollution Analysis, McGraw-Hill Book Co., New York.

Norton, W. R., L. A. Roesner, D. E. Evenson and J. R. Monser. 1974. "Computer Program Documentation for the Stream Quality Model QUAL-II," Prepared for the U.S.E.P.A. Systems Development Branch, Washington, D. C.

O'Conner, D. and W. Dobbins. 1956. "The Mechanism of Reaeration in Natural Streams," Journal of the Sanitary Engineering Division ASCE, SA6, 1115-1-1115-30.

Streeter, H. and E. Phelps. 1925. "A Study of the Purification of the Ohio River," U. S. Public Health Service Bull. No. 146, Washington, D. C.

Tabatabaie, M. 1977. Unpublished rough draft of M.S. thesis, Dept. of Environmental Engineering, Illinois Institute of Technology.

Thomann, R. V. 1972. Systems Analysis and Water Quality Management, McGraw-Hill Book Co., New York.

Velz, C. J. 1970. Applied Stream Sanitation, John Wiley & Sons, Inc., New York.

Whipple, W., F. P. Coughlan and S. L. Yu. 1970. "Instream Aerators for Polluted Rivers," Journal of the Sanitary Engineering Division ASCE, 96(SA5):1153-1165.

APPENDIX A

Subroutine STREAM

```
C
C            RECEIVING STREAM
C
      SUBROUTINE STREAM
C
C            COMMON INITIAL STATEMENTS
C
      COMMON SMATX(20,30),TMATX(20,30),DMATX(20,20),OMATX(20,20),IP(20),
     1INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(20,5),COSTO(20,5),ACOST(20,5)
     2,TCOST(20,5),DHR,PCT,WPI,CLAND,DLAND,PROCNO(10),FLOW(25),POW(25),T
     3KWHD(25)
      WRITE (IO,10)
   10 FORMAT (1H1,48X,'INSTREAM  DISSOLVED  OXYGEN ')
      WRITE (IO,20)
   20 FORMAT (/////4X,'REACH',10X,'PHYSICAL   CHARACTERISTICS',16X,'VARI
     1ABLE   CHARACTERISTICS',15X,'TRIBUTARY   CHARACTERISTICS')
      WRITE (IO,30)
   30 FORMAT (/4X,'*****',5X,'***********************************',7X,'
     1*********************************',9X,'*************************
     2*******')
      WRITE (IO,40)
   40 FORMAT (/14X,'LENGHT   DEPTH   CROSS SEC   K1   ',8X,'MINIMUM   EN
     1D   END     FLOW     TEMP',9X,'DO     BOD     FLOW     TEMP')
      WRITE (IO,50)
   50 FORMAT (33X,'AREA',21X,'DO',6X,'DO',4X,'BOD')
      WRITE (IO,60)
   60 FORMAT (15X,'(MI)     (FT.)     (SQ.FT.) (1/DAY)',8X,'(MG/L)  (MG/L)
     1 (MG/L)  (CFS)     (C)',9X,'(MG/L)  (MG/L)  (CFS)     (C)')
C
C
C            READ NUMBER OF REACHES AND END PROCESS
C
      READ (INP,70) NREACH,ISTREM,JPROC
   70 FORMAT (3I5)
C
C            READ UPSTREAM CHARACTERISTICS
C
      READ (INP,80) DOUP,BODUP,QUP,TEMPUP
   80 FORMAT (4F10.2)
C
C            READ DOWNSTREAM CHARACTERISTICS FOR NREACH REACHES (LENGHT
C            DEPTH,DEOXYGENATION COEF.,CROSS SECTIONAL AREA,TRIBUTARY
C            FLOW,DO,BOD AND TEMPERATURE
C
      DO 160 I=1,NREACH
      READ (INP,90) RLNGTH,DEPTH,XK1,XAREA,QTRIB,DOTRIB,BODTRB,TEMTRB
   90 FORMAT (8F10.2)
C
C            CONVERT FLOW TO MGD
C
      QUP=QUP/1.54723
      QTRIB=QTRIB/1.54723
      IF (I.GT.1) GO TO 100
      QTRIB=SMATX(2,ISTREM)
      DOTRIB=DMATX(4,JPROC)
      BODTRB=SMATX(6,ISTREM)+SMATX(17,ISTREM)
      TEMTRB=DMATX(5,JPROC)
C
C            MASS BALANCE AT BEGINNING OF REACH
C
  100 Q=QUP+QTRIB
```

APPENDIX A (Cont.)

```
      DO=(DOUP*QUP+DOTRIB*QTRIB)/Q
      BOD=(BODUP*QUP+BODTRB*QTRIB)/Q
      TEMP=(TEMPUP*QUP+TEMTRB*QTRIB)/Q
C
C           CALCULATE VELOCITY IN FT/DAY
C
      VELOC=((Q*1.54723)/XAREA)*86400.
C
C           CALCULATE REAERATION COEF.
C
      XK2=((0.00194*VELOC)**0.5)/(DEPTH**1.5)
C
C           TEMPERATURE ADJUSTMENTS
C
      XK1=XK1*(1.047**(TEMP-20.))
      XK2=XK2*(1.0241**(TEMP-20.))
      SATDO=(14.62-(0.3898*TEMP)+(0.00696*TEMP**2)-(0.00005897*TEMP**3))
      DEFDO=SATDO-DO
C
C           CALCULATE MINIMUM DO
C
      TTIME=RLNGTH*5280./VELOC
      TC=TTIME+1.
      IF ((XK2*DEFDO-XK1*BOD).GT.0.) GO TO 110
      TC=(1./(XK2-XK1))*ALOG((XK2/XK1)*(1.-(XK2-XK1)*DEFDO/(XK1*BOD)))
      AMXDEF=(XK1*BOD)/(XK2-XK1)*(EXP(-XK1*TC)-EXP(-XK2*TC))+DEFDO*EXP(-
     1XK2*TC)
C
C           CALCULATE DO AND BOD AT END OF REACH
C
  110 ENDDEF=(XK1*BOD)/(XK2-XK1)*(EXP(-XK1*TTIME)-EXP(-XK2*TTIME))+DEFDO
     1*EXP(-XK2*TTIME)
      ENDBOD=BOD*EXP(-XK1*TTIME)
      IF (TC.LT.TTIME) GO TO 130
      IF (DEFDO.LT.ENDDEF) GO TO 120
      DOMIN=DO
      GO TO 140
  120 DOMIN=SATDO-ENDDEF
      GO TO 140
  130 DOMIN=SATDO-AMXDEF
  140 IF (DOMIN.LT.0.) DOMIN=0.
C
C           CONVERT FLOW TO CFS
C
      QTRIB=QTRIB*1.54723
      Q=Q*1.54723
C
C           OUTPUT
C
      ENDDO=SATDO-ENDDEF
      IF (ENDDO.LT.0.) ENDDO=0.
      WRITE (IO,150) I,RLNGTH,DEPTH,XAREA,XK1,DOMIN,ENDDO,ENDBOD,Q,TEMP,
     1DOTRIB,BODTRB,QTRIB,TEMTRB
  150 FORMAT (/4X,I3,2X,F9.2,4X,F6.2,1X,F10.2,3X,F4.2,10X,F5.2,2X,F6.2,F
     17.2,1X,F8.2,4X,F5.2,5X,F6.2,3X,F6.2,F8.2,2X,F6.2)
C
C           INTIALIZE FOR NEXT REACH
C
      DOUP=ENDDO
      BODUP=ENDBOD
      QUP=Q
      TEMPUP=TEMP
  160 CONTINUE
      RETURN
      END
```

APPENDIX B

Example of Input Data for Subroutine STREAM

	Col. 1-5	Col. 6-10	Col. 11-15
Card 1	4	16	6

	Col. 1-10	Col. 11-20	Col. 21-30	Col. 31-40	Col. 41-50	Col. 51-60	Col. 61-70	Col. 71-80
Card 2	9.0	3.0	500.	15.				
Card 3	3.1	6.9	0.28	771.				
Card 4	7.8	11.9	0.33	2462.	160.	3.0	7.0	18.
Card 5	7.1	13.0	0.30	2500.	30.	8.0	2.9	19.
Card 6	2.7	15.0	0.22	2700.	50.	7.0	2.0	15.

Note: The input data for STREAM follows the normal data sequence for EXECMAIN

```
                                        INSTREAM  DISSOLVED  OXYGEN


REACH       PHYSICAL   CHARACTERISTICS                    VARIABLE   CHARACTERISTICS                     TRIBUTARY   CHARACTERISTICS
*****  ***********************************       **********************************       ******************************
         LENGHT     DEPTH    CROSS SEC     K1      MINIMUM    END      END       FLOW       TEMP     DO      BOD       FLOW      TEMP
                              AREA                   DO       DO       BOD
          (MI)      (FT.)    (SQ.FT.)   (1/DAY)    (MG/L)   (MG/L)   (MG/L)     (CFS)       (C)     (MG/L)   (MG/L)    (CFS)      (C)
   1      3.10       6.90     771.00      .23       7.27     7.27     7.79     654.46      16.18    2.00     25.06    154.46     20.00
   2      7.80      11.90    2462.00      .28       4.91     4.91     5.09     814.46      16.54    3.00      7.00    160.00     18.00
   3      7.10      13.00    2500.00      .26       4.57     4.57     3.60     844.46      16.63    8.00      2.90     30.00     19.00
   4      2.70      15.00    2700.00      .19       4.55     4.55     3.26     844.46      16.63    7.00      2.00       .00     15.00
```

APPENDIX B

Example of Output
for Subroutine STREAM